

Recent Fan Broadband Noise Activities within the Framework of European Funded Collaborative Research Projects

Lars Enhardt, DLR – German Aerospace Center
Engine Acoustics, Berlin

21st CEAS-ASC Workshop, Dublin

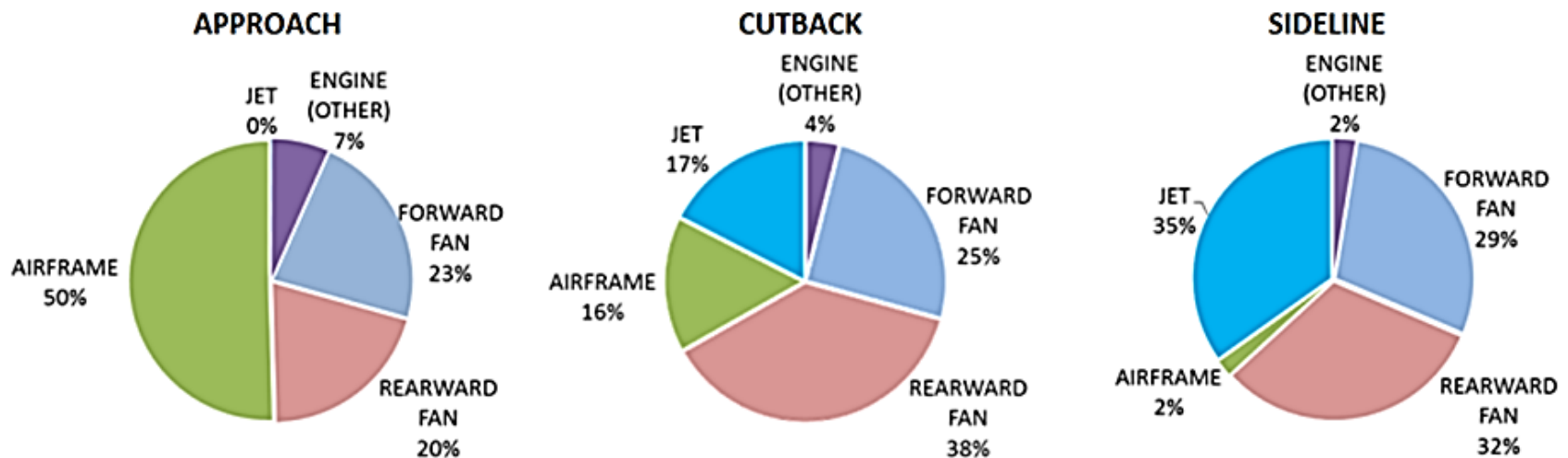


Knowledge for Tomorrow

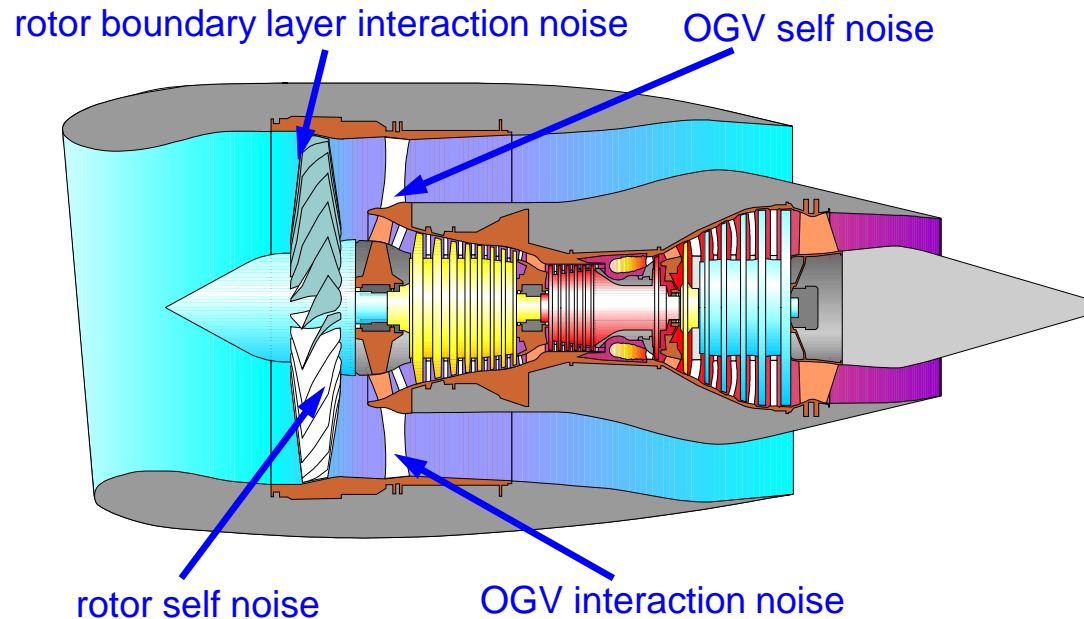


Motivation – *Why* Research on Fan Broadband Noise?

- **Air traffic is predicted to grow by 5% per year** in the short and medium term.
- **Noise remains** one of the most significant factors of **limitation for air transport growth** in Europe (and the rest of the world)
- **Technology advances are required** to achieve this growth without unacceptable levels of noise in particular at airport surroundings.
- **Fan broadband noise is one of the most important noise sources of modern aircraft.**



Motivation – *Where are the sources?*



Interaction mechanisms

- The blade-tip of the rotor fan and the turbulent boundary layer in the inlet-duct
- **rotor boundary layer interaction noise**
- Turbulent eddies convected in the rotor boundary layer and the rotor trailing edge
- **rotor self noise**
- The rotor wake and the downstream outlet guide vanes - **OGV interaction noise**
- Turbulent eddies convected in the vane boundary layer and the vane trailing edge
- **OGV self noise**



Motivation – *What* do we want to achieve?

- Physical understanding of the broadband noise source mechanisms
- Development of validated tools allowing advanced, large scale CFD
- Prediction capability for broadband noise to develop low broadband noise fan concepts
- Design noise reduction concepts and associated devices able to reduce fan broadband noise at source
- Assess the noise reduction concepts by conducting (lab-scale) experiments and numerical simulations
- Develop understanding of the mechanisms involved and extrapolate the results to the aero-engine environment
- Deliver reliable prediction methodologies and noise reduction technologies to design low-broadband-noise aircraft fans
- Acquisition of an experimental database to validate the CFD and CAA simulations from the sound sources to the radiation



Outline - European research dedicated to fan broadband noise

- **PROBAND**

- Chosen key results
- Summary of outcome

- **FLOCON**

- Chosen key results
- Summary of outcome

- **TurboNoiseBB**

- Project description
- Anticipated results





PROBAND - Improvement of Fan Broadband Noise Prediction



PROBAND



EU Framework 6 Research

Consortium:

DLR - Deutsches Zentrum für Luft und Raumfahrt (DE)
RR - Rolls-Royce plc (UK)
SnM - Snecma Moteurs (FR)
ECL - Ecole Centrale de Lyon (FR)
Flu - Fluorem SAS (FR)

ONERA - Office National d'Études et Recherches
Aérospatiales (FR)

UPMC - Université Pierre et Marie Curie (FR)

ISVR - Institute of Sound and Vibration Research (UK)

UCAM - University of Cambridge (UK)

TUB - Technische Universität Berlin (DE)

VKI - Von Karman Institute (BE)

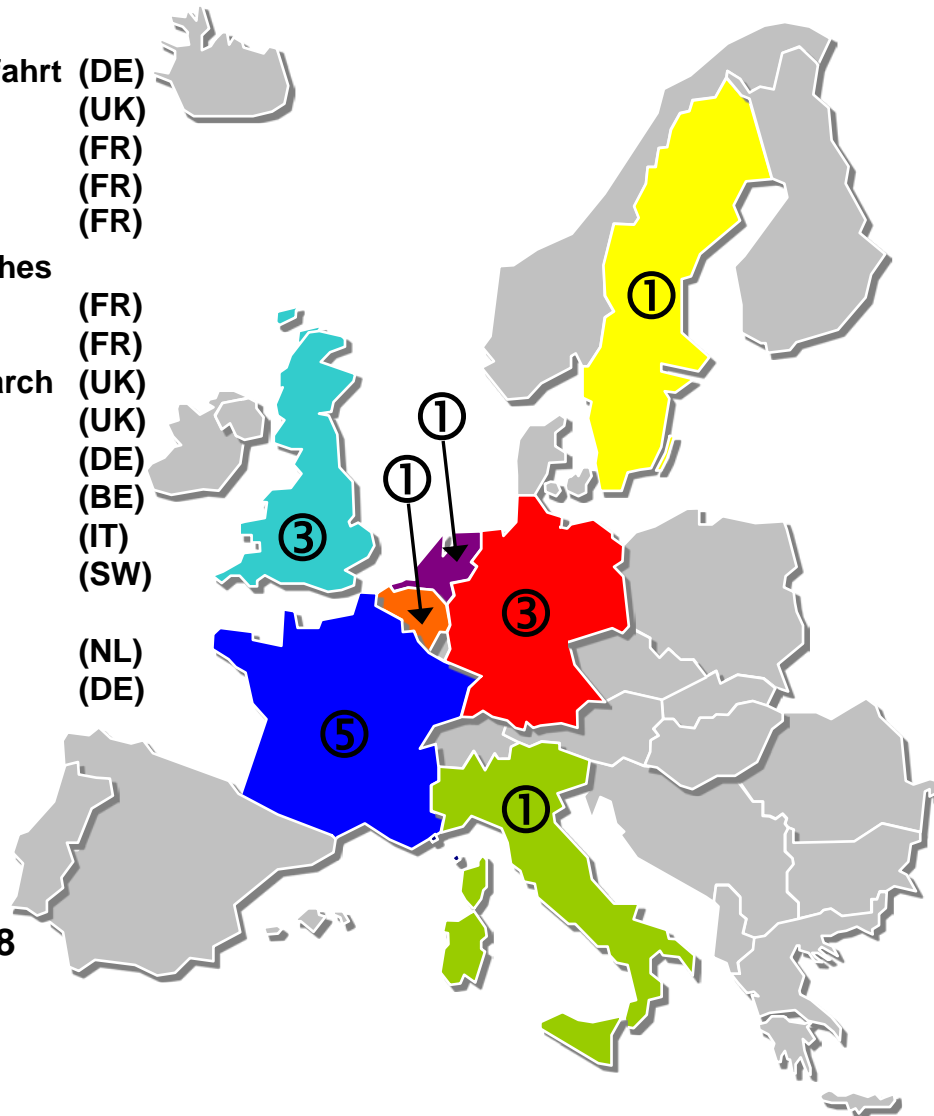
UR3 - Università Roma Tre (IT)

KTH - Kungliga Tekniska Högskolan (SW)

NLR - Nationaal Lucht- en Ruimtevaart

Laboratorium (NL)

ACAT - Anecom Aerotest (DE)



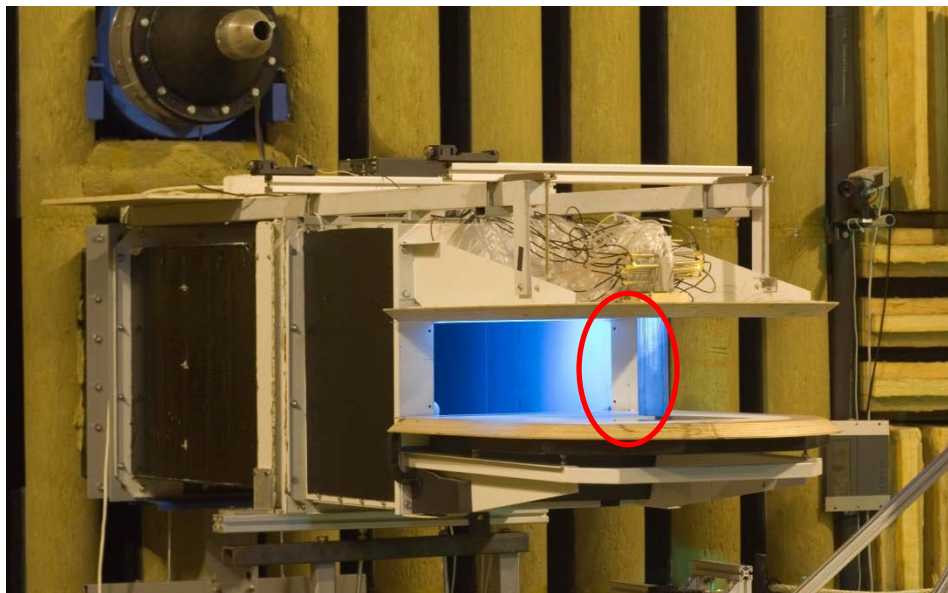
- Budget: 5 M€
- Project start: 1. April 2005
- Project end: 31. Dezember 2008
- Duration: 3,75 years



Single Airfoil experiment (ECL)



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- TE noise
- Tip/casing noise

Measurements

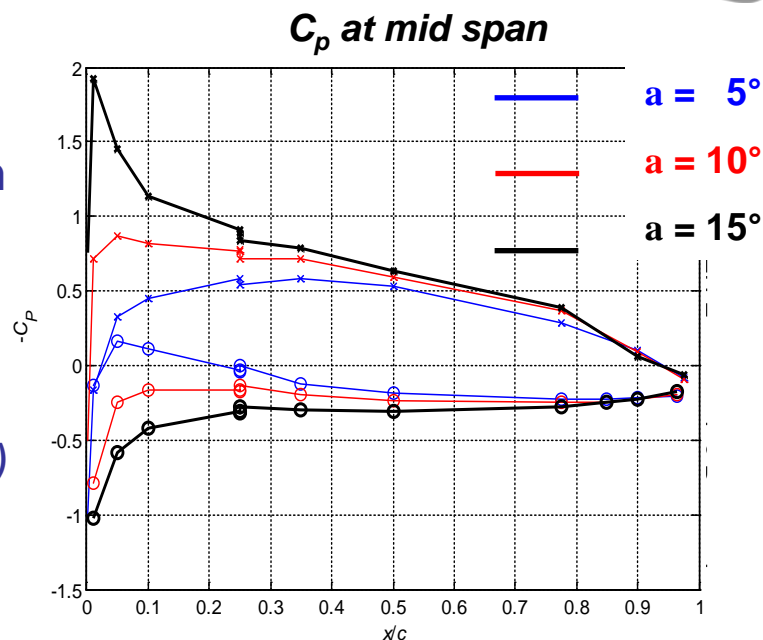
- PIV, LDA, HWA
- Wall pressure
- Far field
- Combined measurements

Features

- NACA5510: $c = 200$ mm ; span: 200mm
- High lift: 5% camber and 15° AoA
- Gap: $h \sim 10$ mm = 5% c
- $U_0 = 70$ m/s ($M \sim 0.2$; $Re_c \sim 9.3 \cdot 10^5$)
- Low turbulence inflow (0.7%)
- Incoming TBL: $d \sim 1.8h$ (99% thickness)



Variations of parameters: U_0 , AoA and h





Single Airfoil experiment, PIV and HWA (ECL)



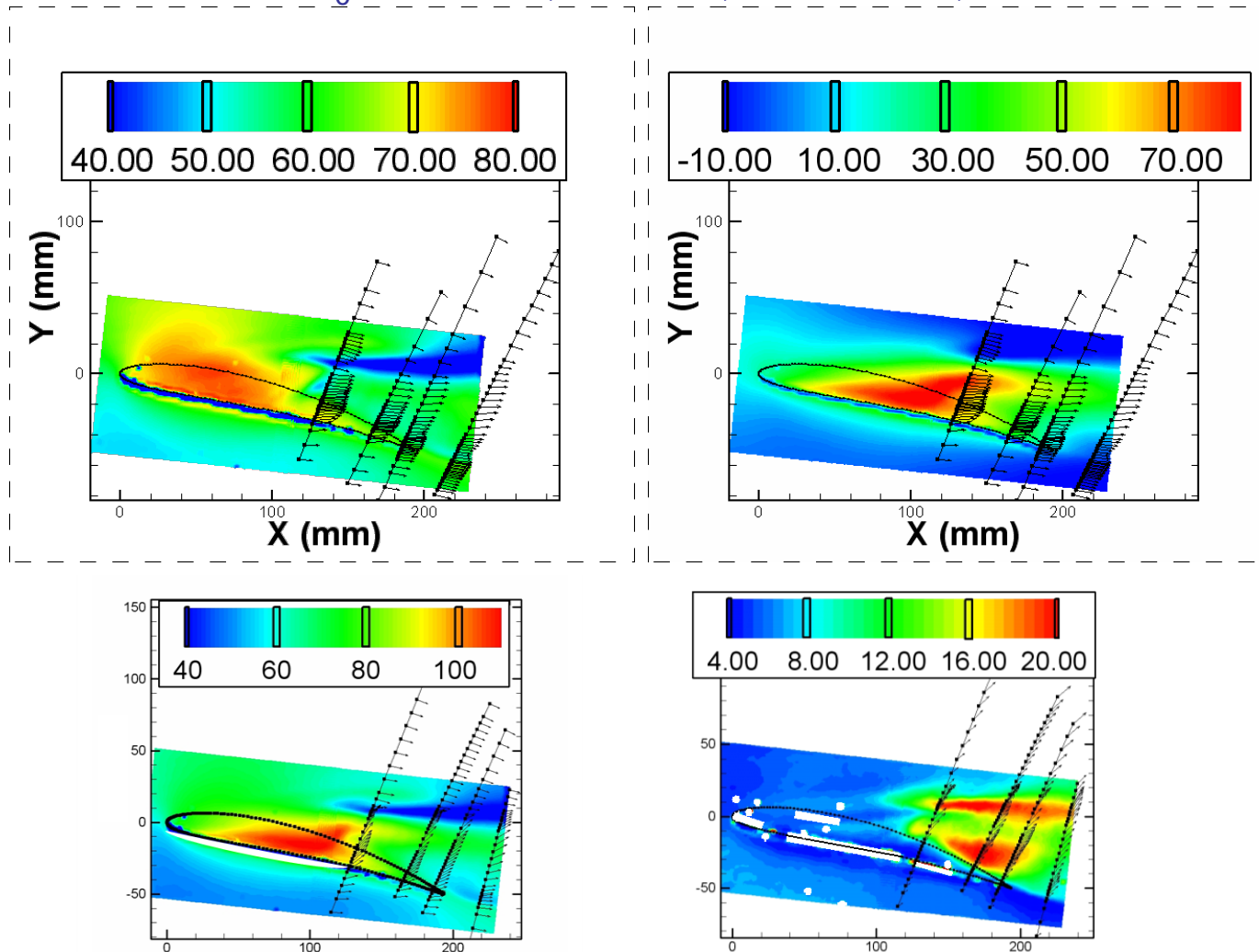
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Steady Flow in gap region : mid-gap section

$U_0 = 70$ m/s ; $\alpha = 15^\circ$; $h = 10$ mm ;





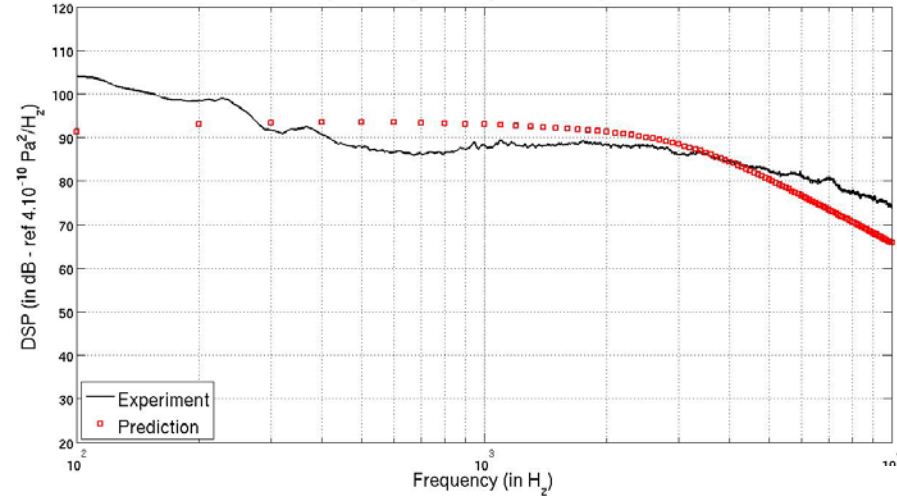
BBN modeling: Application (ECL)



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Wall pressure spec. predicted from
RANS

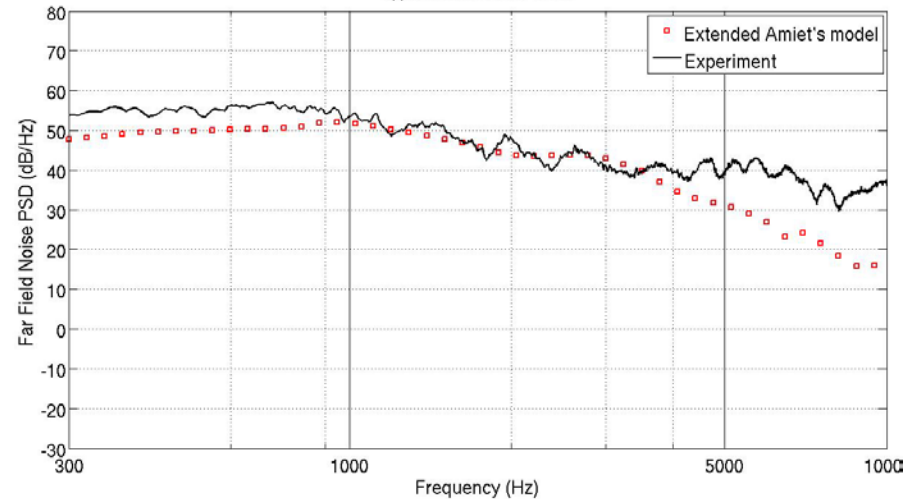
Wall-pressure spectra: experiment and prediction



TE
model

Exp. data: Far field

Spp calculated at $x/C = 97.5\%$



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CFD on Selfnoise (TUB)

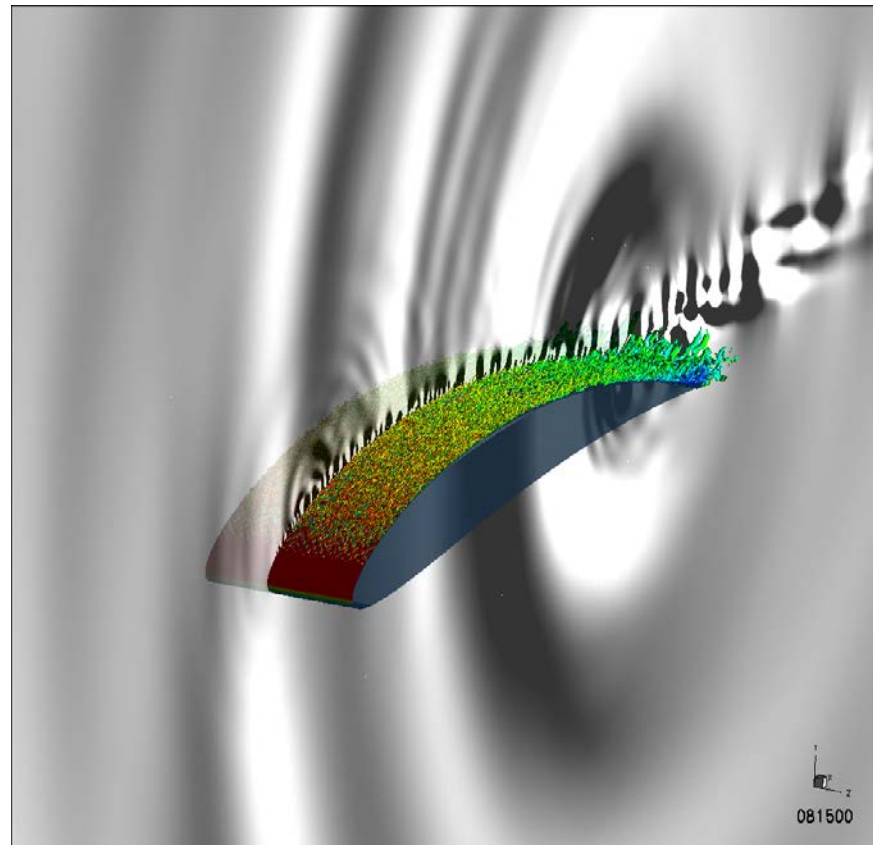
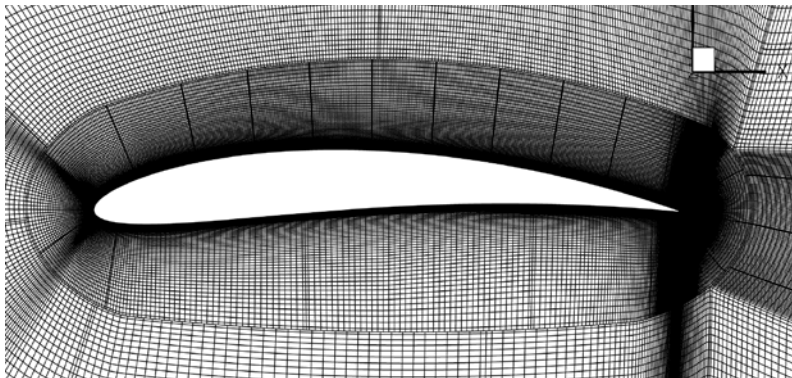


• Simulation of boundary layer broadband noise with IDDES

- grid: 5.3 million cells
 - 40 cells in span wise
- span wise extent 1cm ($d/c = 0.05$)
- LES like grid on suction side
 - $dx = 2 \cdot dz = 0.5$ mm
- coarser grid on pressure side

Vortex structures colored with velocity magnitude (λ_2),
on slice: visualization of radiated sound (dp/dt)

Grid slice



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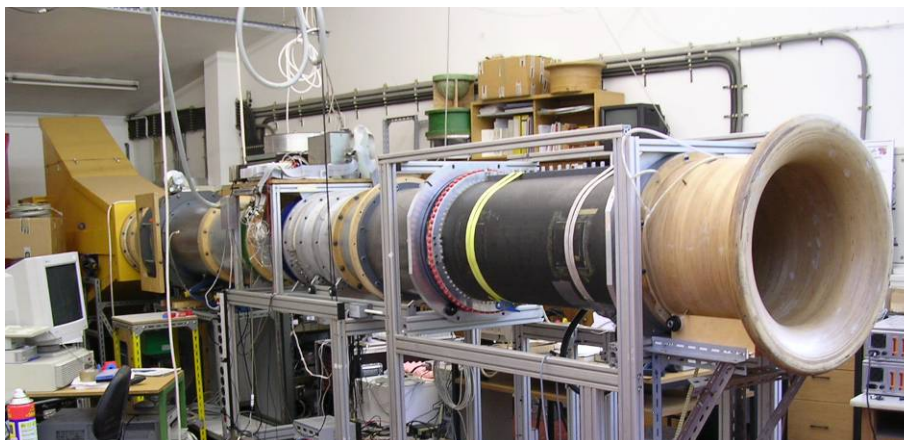


Setup of laboratory scale experiment (DLR)



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Low speed lab scale fan rig (DLR Berlin)



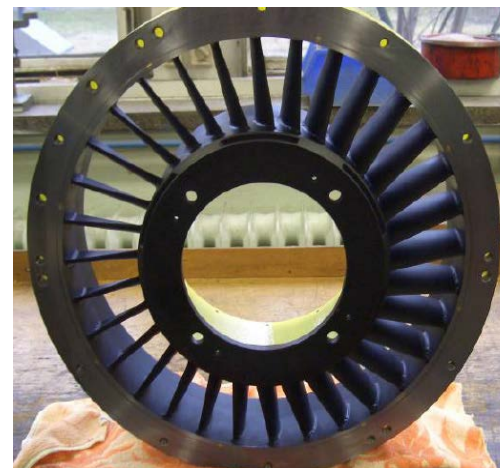
$D = 0.5 \text{ m}$
 $M_{tip} = 0.22$
 $Re = 220000$



24-blade
rotor



16-vane
stator



32-vane
stator



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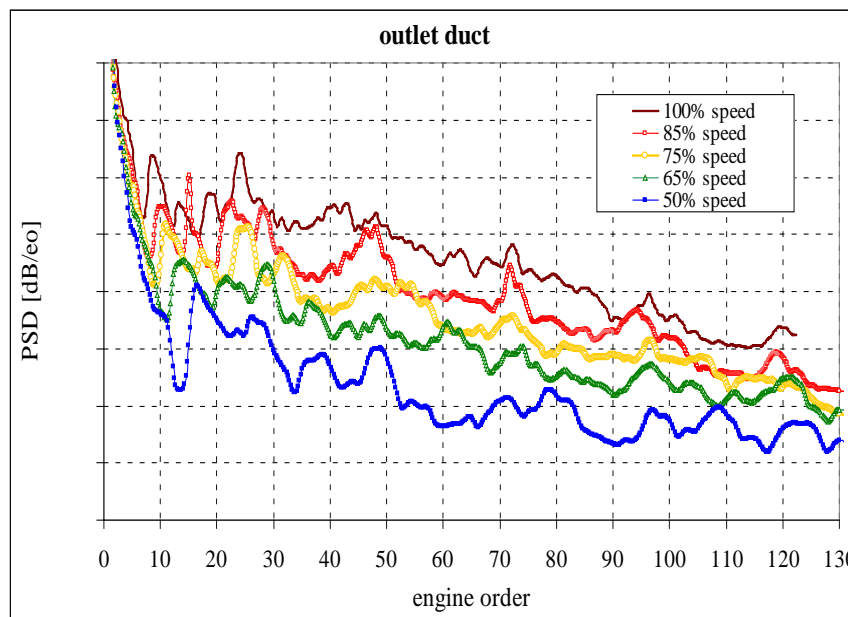
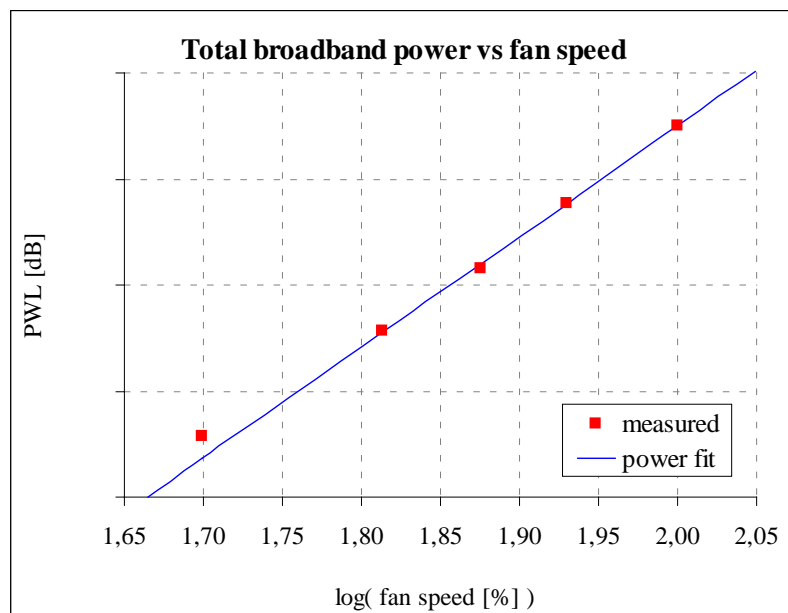


Experimental result: Effect of fan speed (DLR)



Effects on acoustic spectra:

- Max. levels near Blade Passing Frequency
- Nearly constant decay
- Increasing levels with increasing speed



$$P_{BBN} \propto U_{tip}^{5.2}$$

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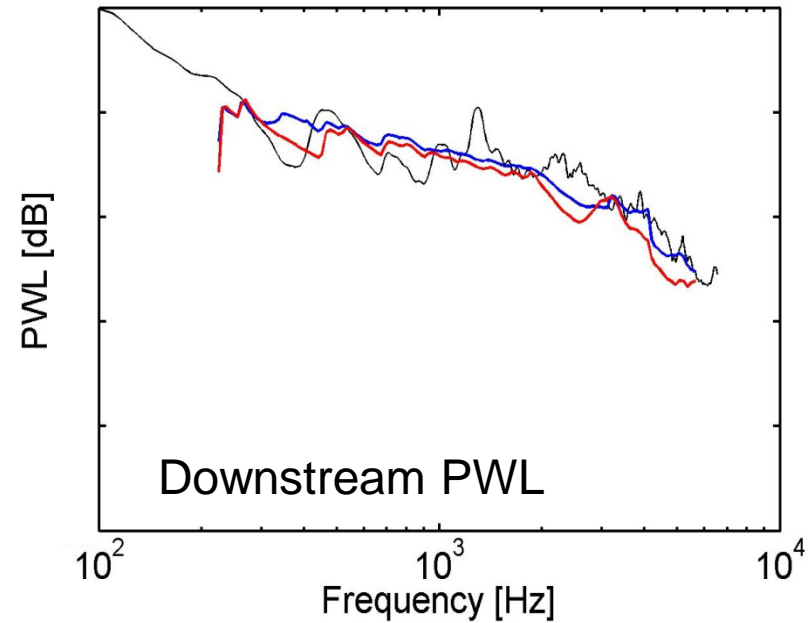
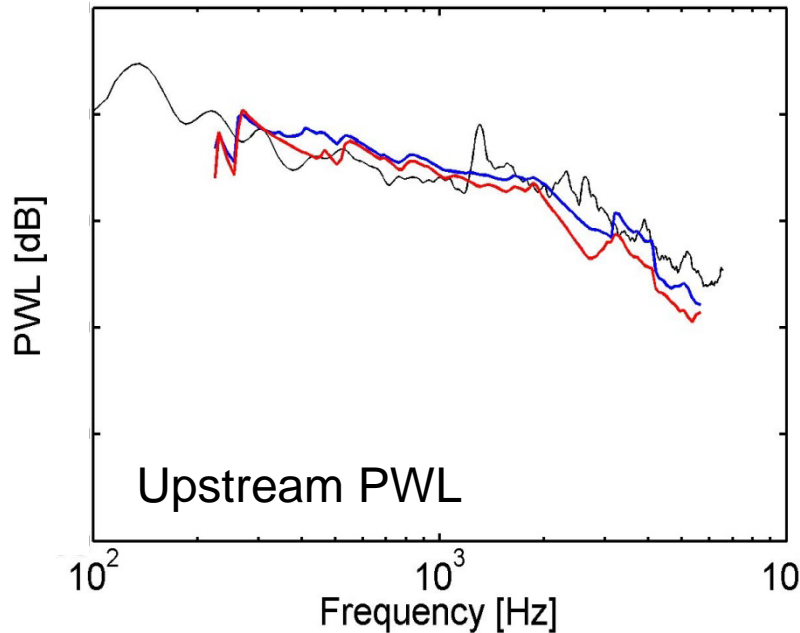
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(Semi)analytical modelling (ISVR, RR)



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The broadband noise model was fed with Tu-levels from the **experiments** and with the outcome of a **RANS calculation**.



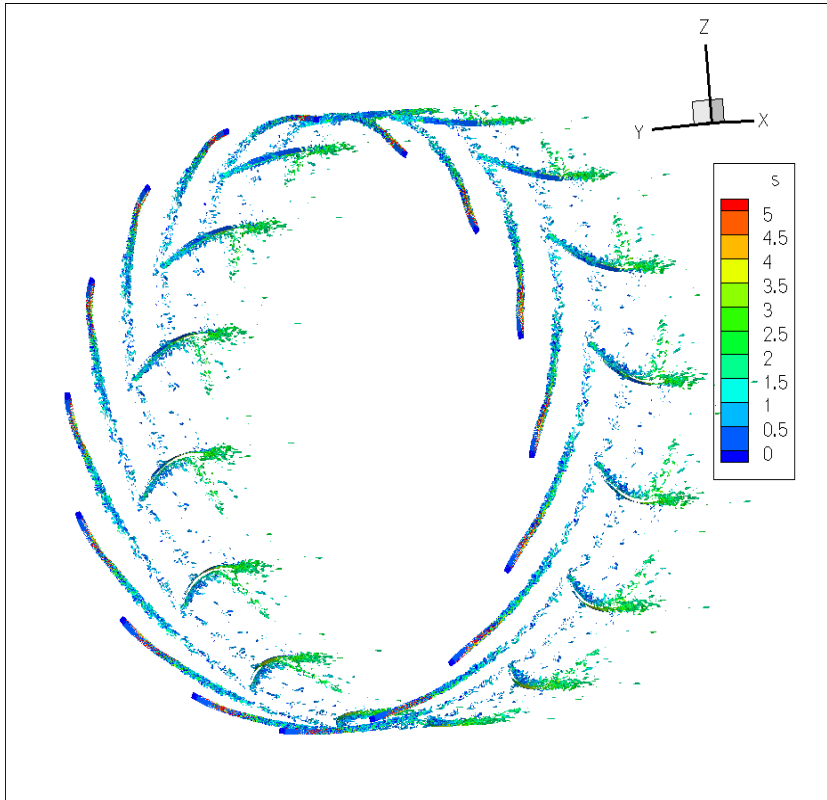
EU Framework 6 Research



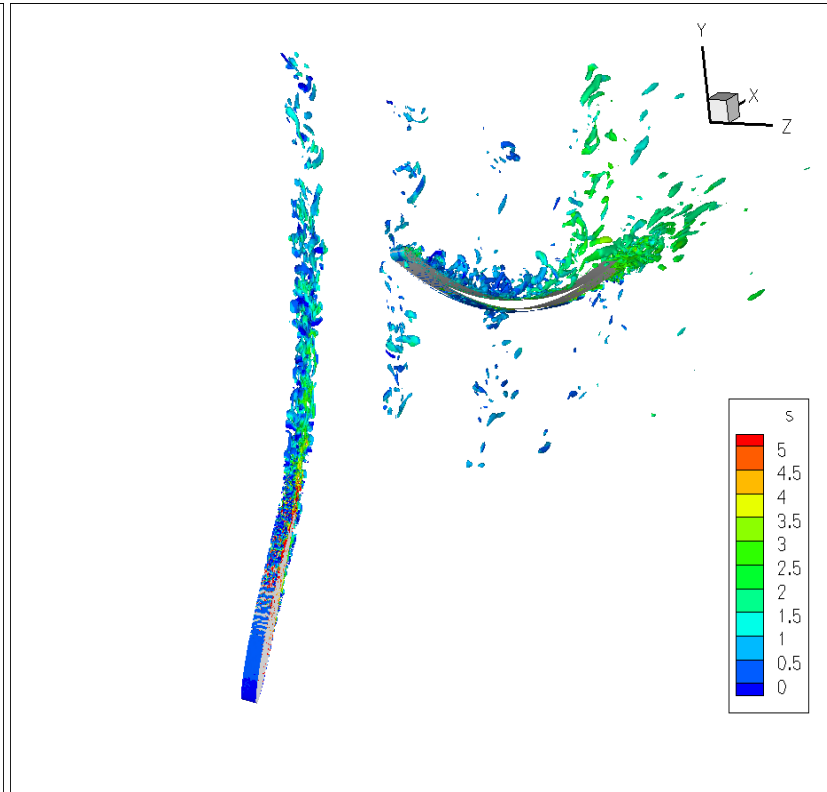
LES computations (ONERA)



Rotor-stator interaction



Close view of
blade-vane interaction



Iso-surface of Q colored by entropy

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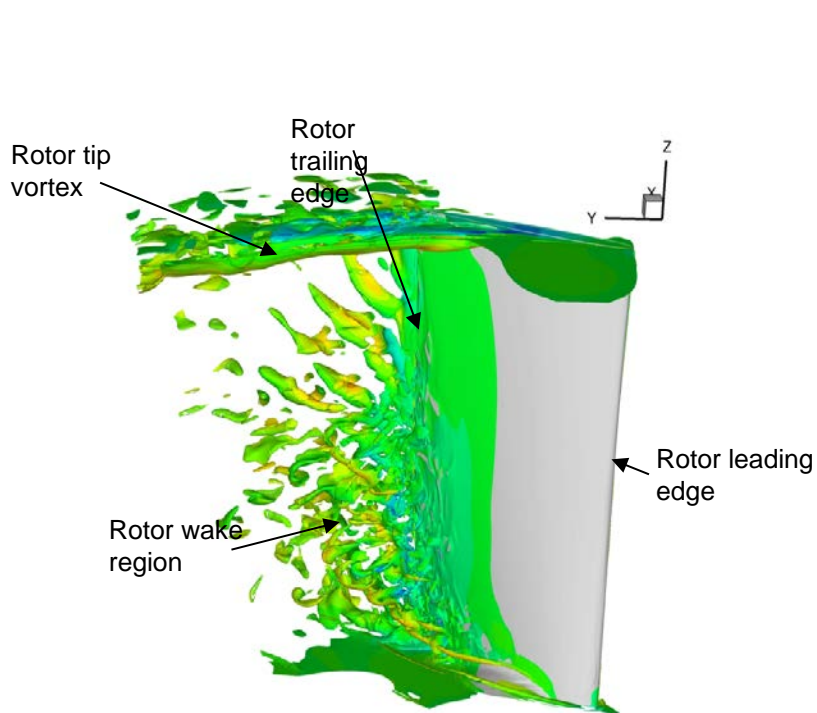
EU Framework 6 Research



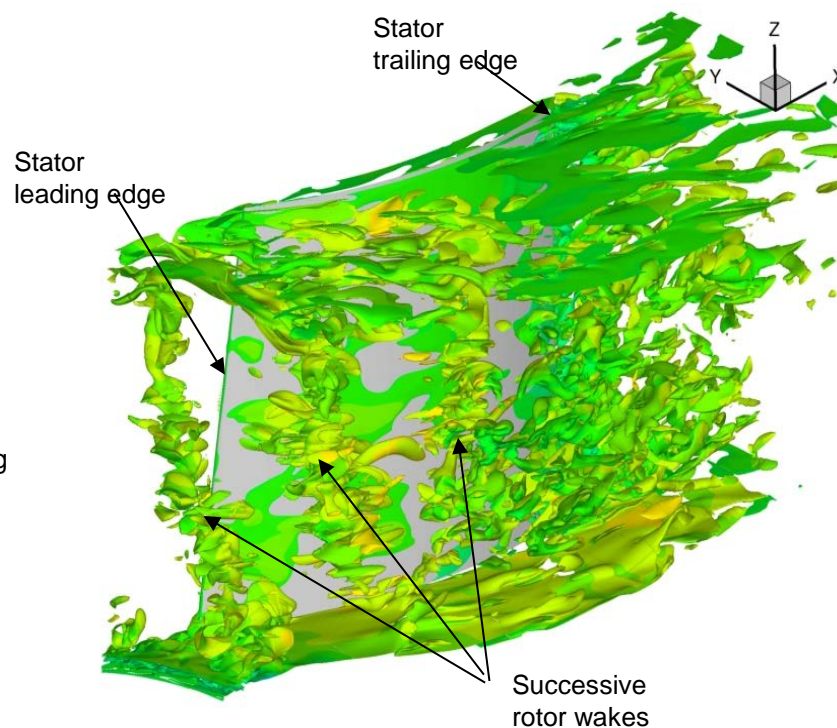
LES computations (DLR)



Computed turbulent flow structures



Iso-surfaces of the axial component of vorticity in rotor system.



Iso-surfaces of the axial component of vorticity in stator system.

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Summary: Final results

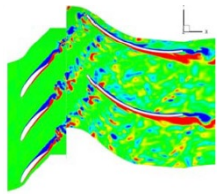


PROBAND

- Physical understanding of the source mechanisms **self noise, interaction noise, and tip clearance noise**. The fundamental experiments provided, in conjunction with advanced CFD, a deeper insight into the flow physics in the source regions.
- **Validated tools** were developed **for** large scale advanced **CFD of fan broadband noise sources**
- The **prediction capability for broadband noise** was **enhanced** with the scope to develop low broadband noise fan concepts.



EU Framework 6 Research



FLOCON

EU FP7, 1st Call, Level 1 Project



Consortium

Research centers:

DLR - Deutsches Zentrum für Luft und Raumfahrt	(DE)
ONERA - Office National d'Études et Recherches Aérospatiales	(FR)
ISVR - Institute of Sound and Vibration Research	(UK)
NLR - Nationaal Lucht- en Ruimtevaart Laboratorium	(NL)

Industrial partners:

Snecma Moteurs	(FR)
Rolls-Royce plc	(UK)
EADS Innovation Works	(DE)
MTU Aero Engines	(DE)
VOLVO Aero Corporation	(SW)
AVIO SpA	(IT)

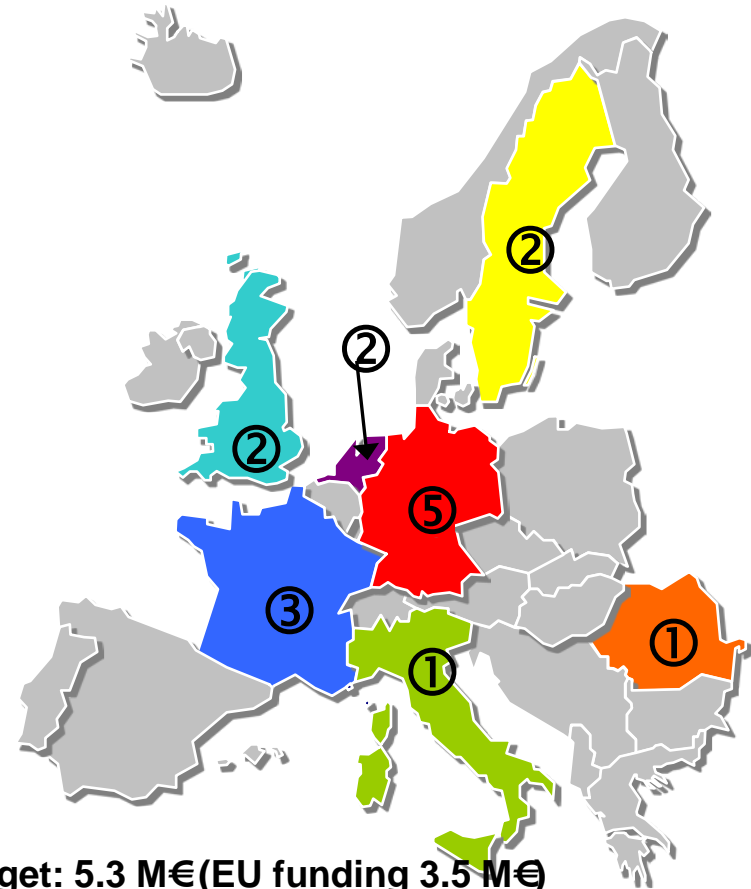
Universities:

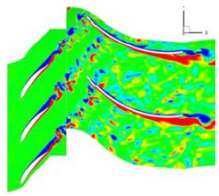
Ecole Centrale de Lyon	(FR)
Universität Siegen	(DE)
Chalmers University of Technology	(SW)
Technische Universität Berlin	(DE)

SME:

Fluorem SAS	(FR)
Microflown Technologies BV	(NL)
Sandu M. Constantin PF	(RO)

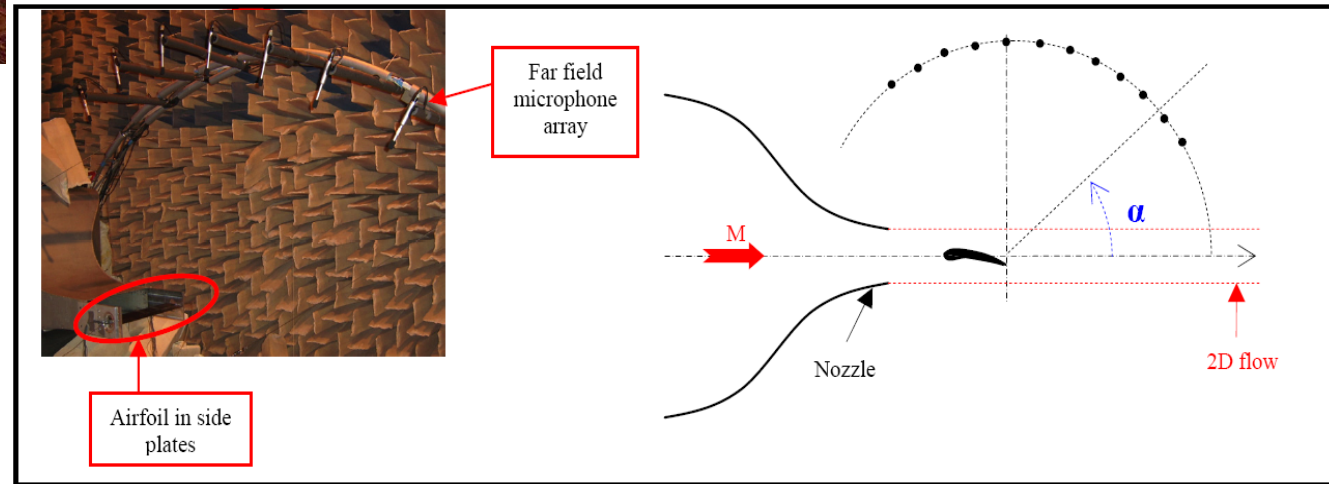
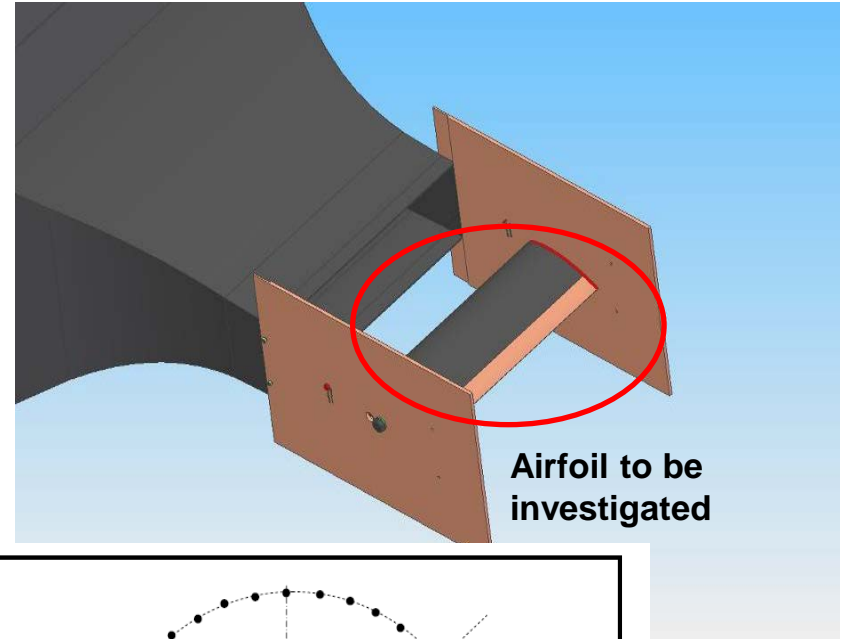
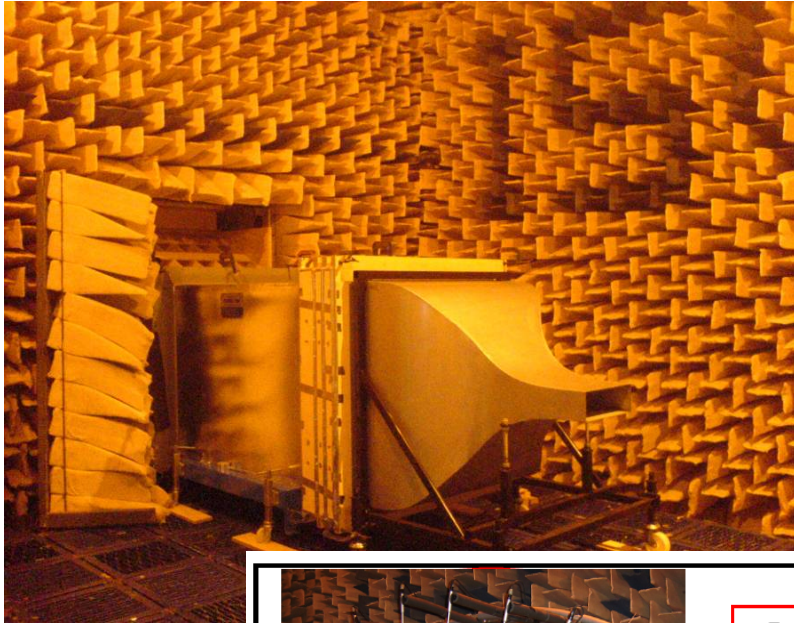
- Budget: 5.3 M€ (EU funding 3.5 M€)
- Project start: 1. September 2008
- Duration: 4 years
- Coordination: DLR Berlin

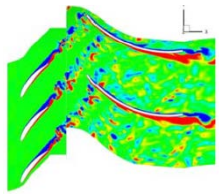




FLOCON

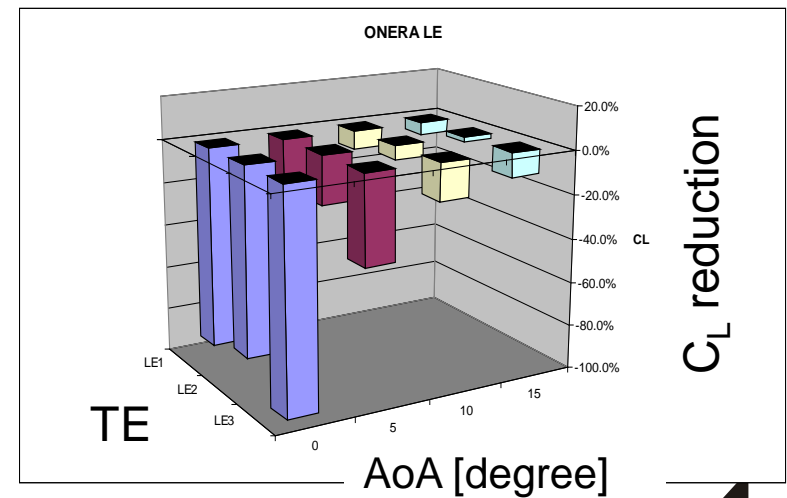
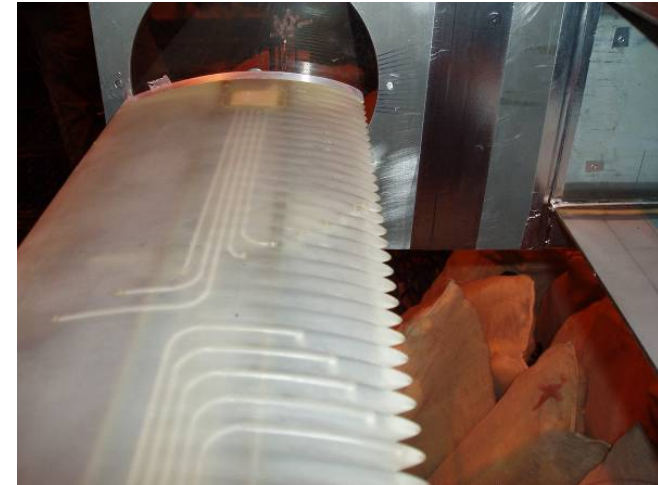
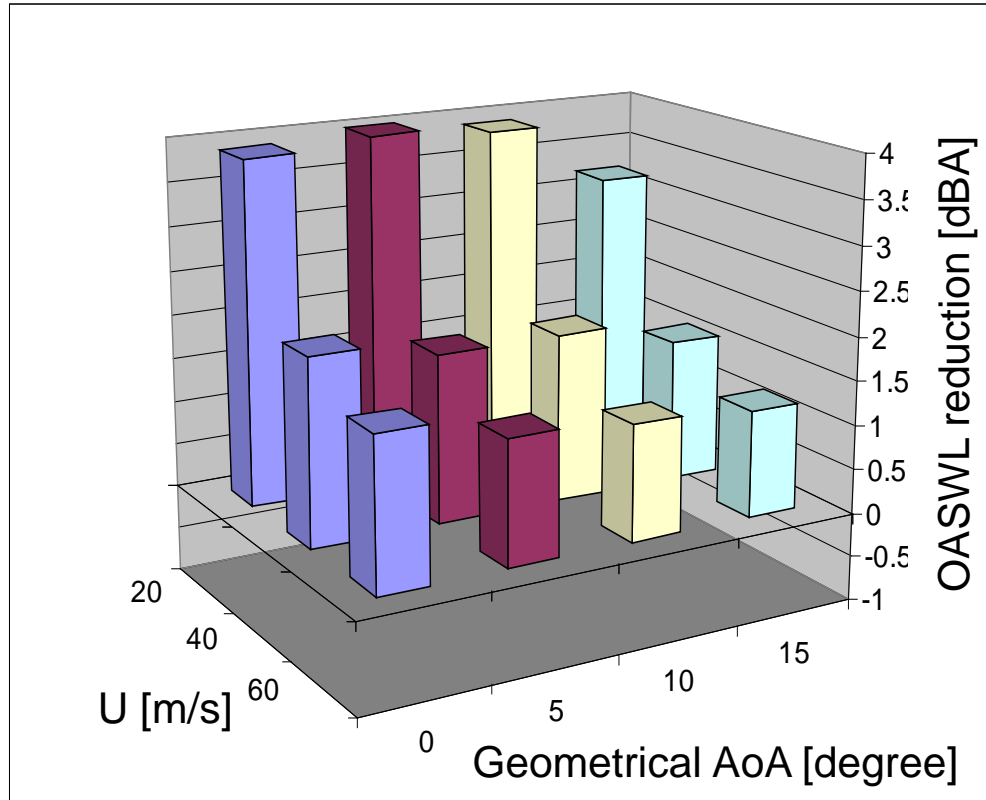
ISVR open jet wind tunnel





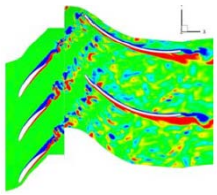
FLOCON

Leading edge treatment



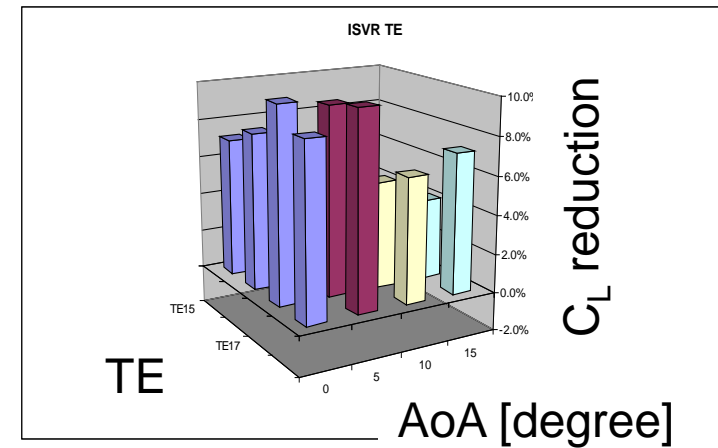
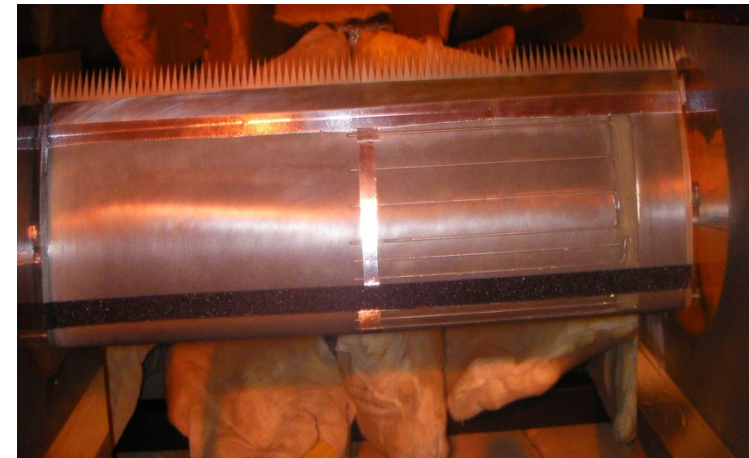
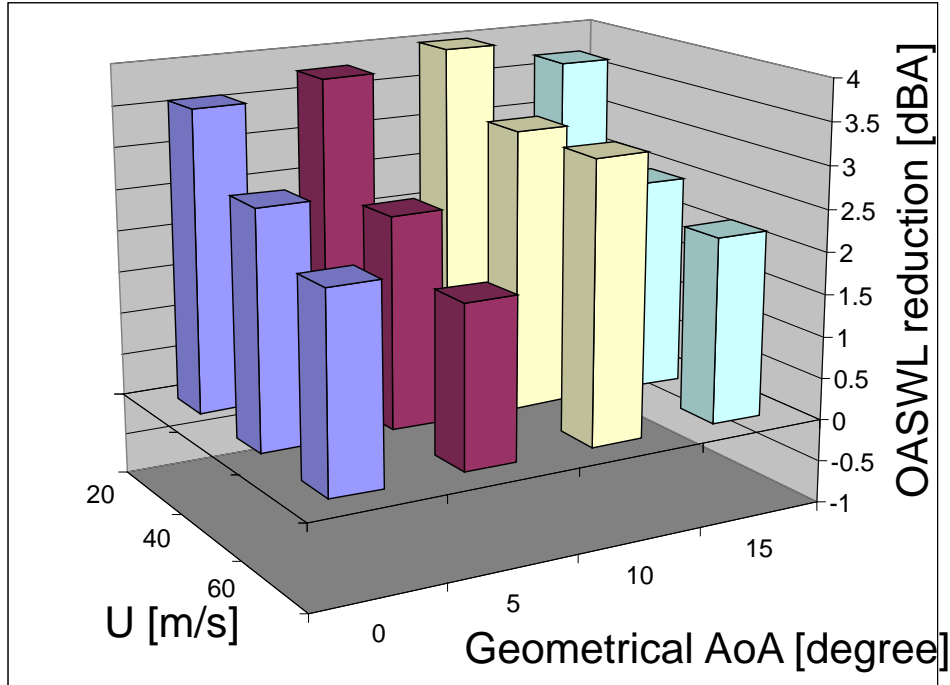
**Downselect of best LE treatment:
ONERA wavy pattern**





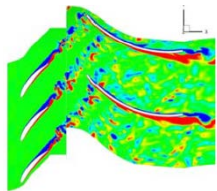
FLOCON

Trailing edge treatment



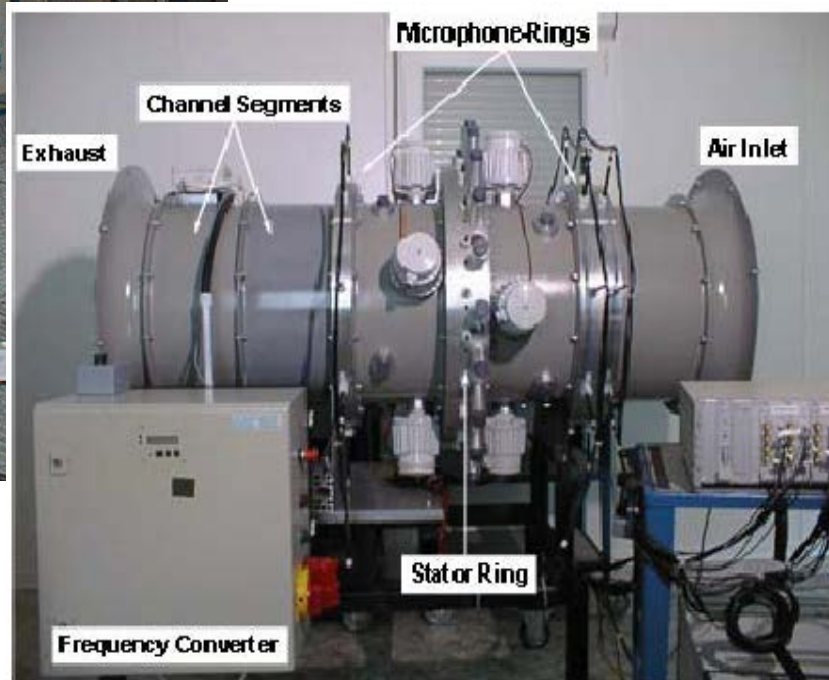
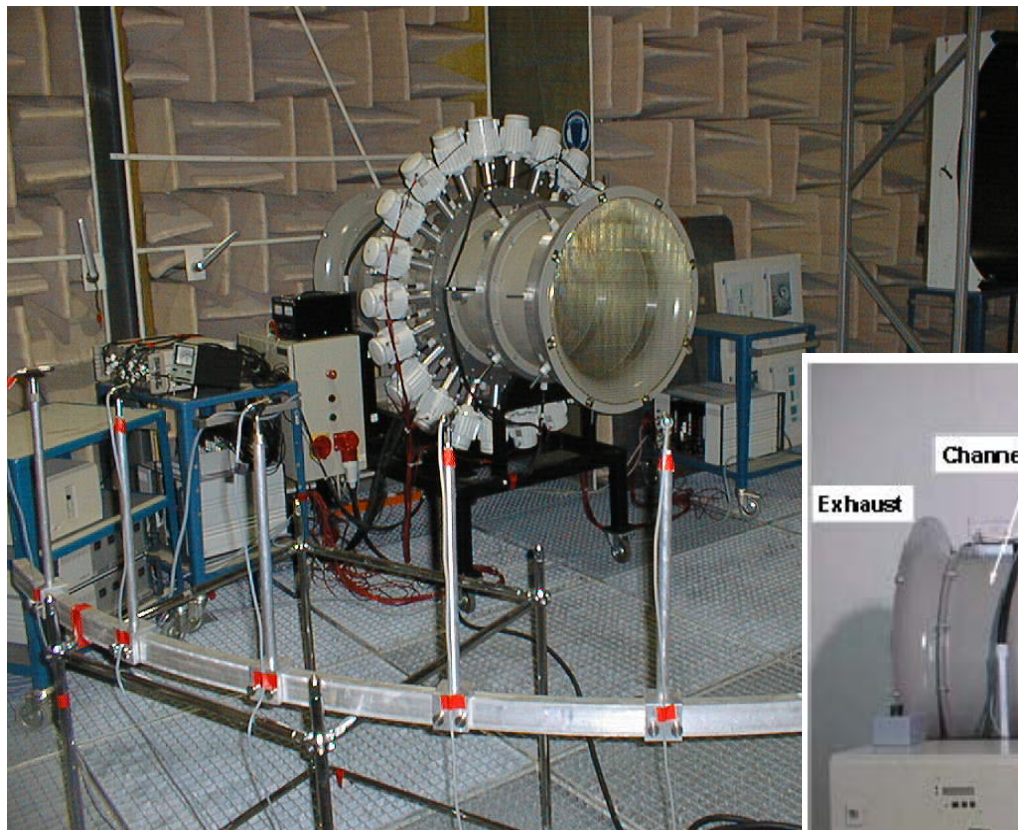
**Downselect of best TE treatment:
ISVR serrated edge most effective**

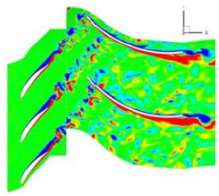




FLOCON

EADS low speed fan rig



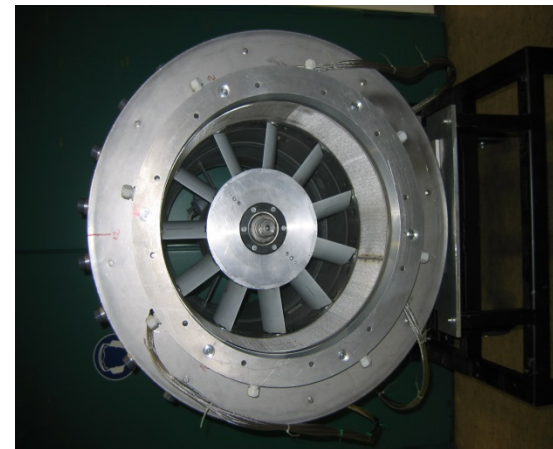
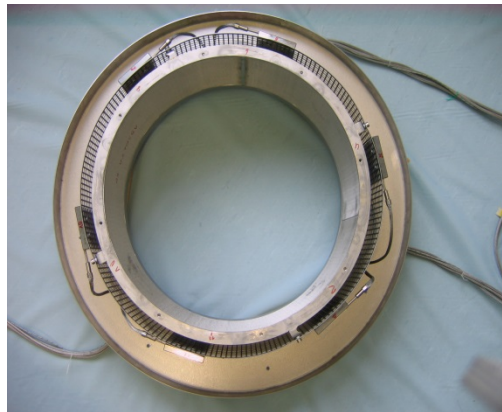
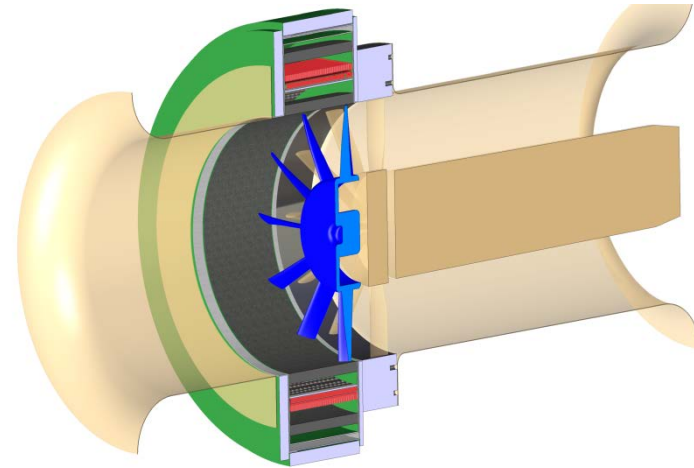
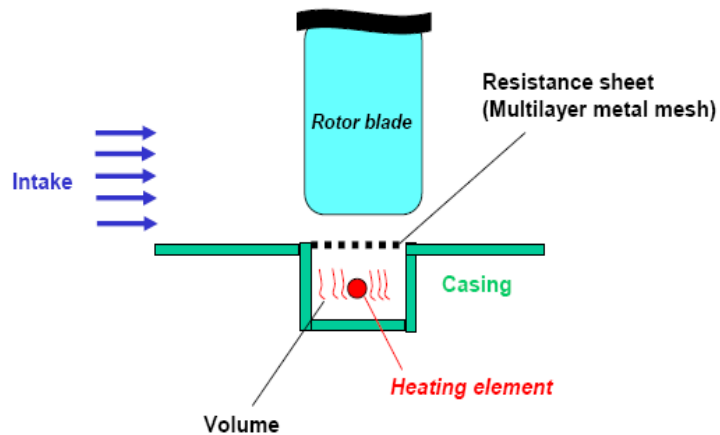


FLOCON

Overtip treatment

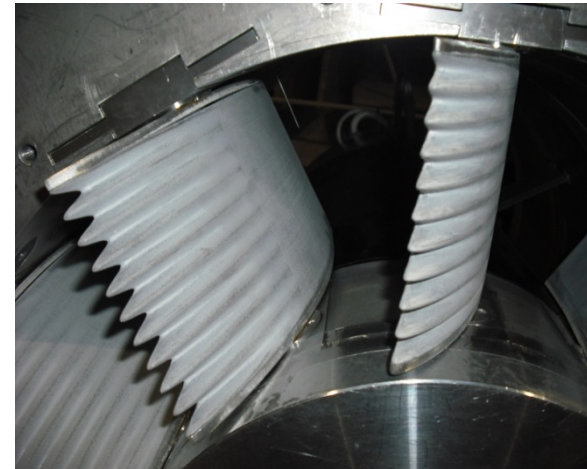
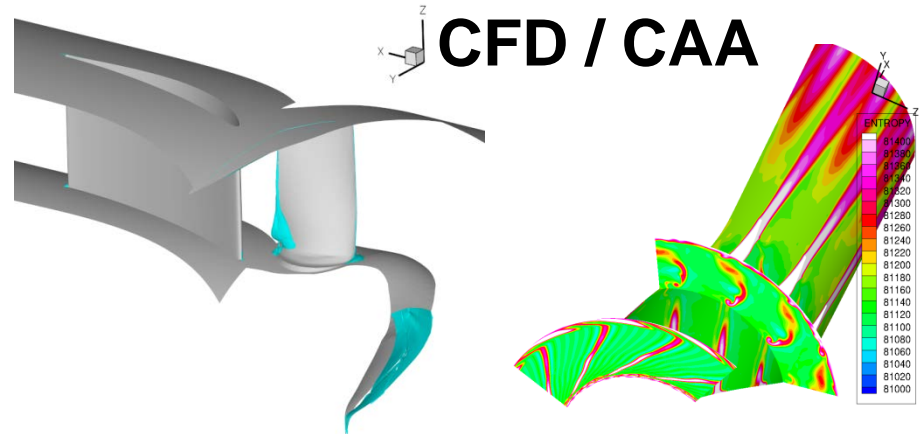
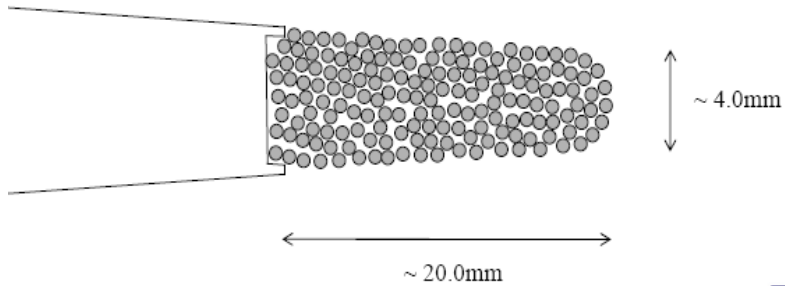


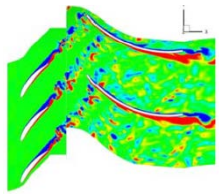
Tuneable Overtip Acoustic Treatment



OGV Treatment

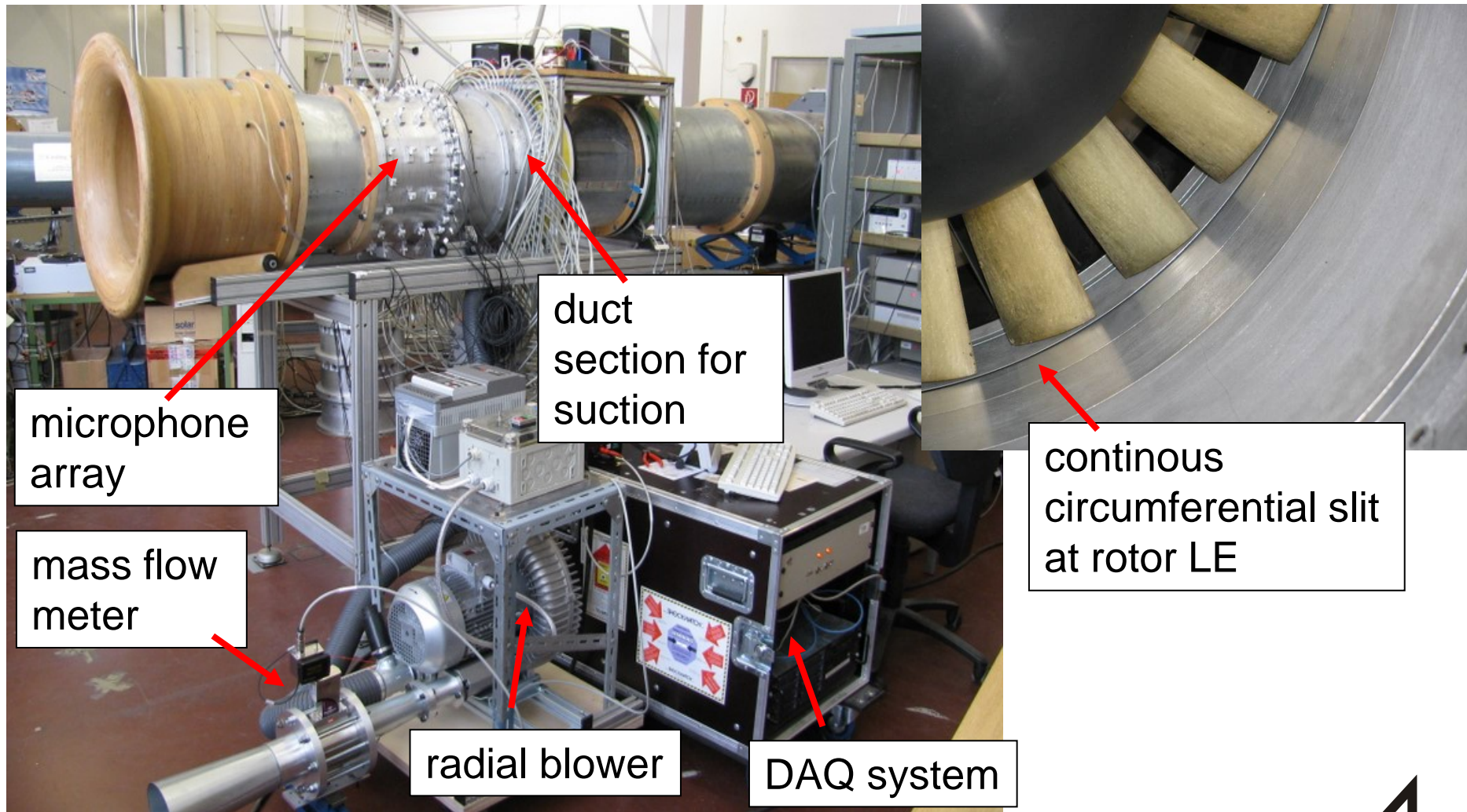
Porous Trailing Edge
Sinter metal spheres



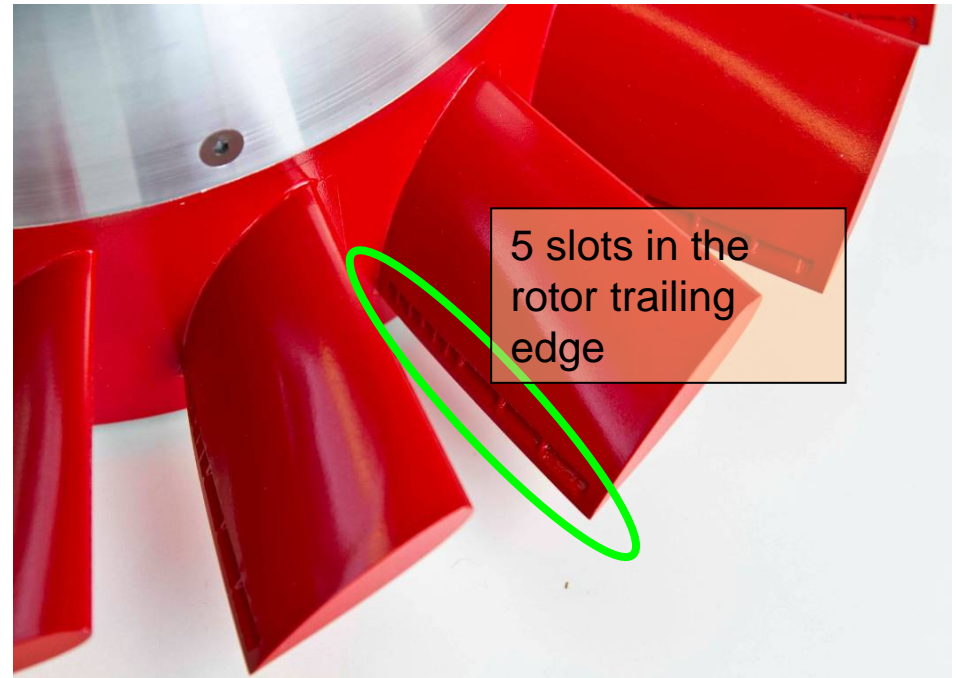
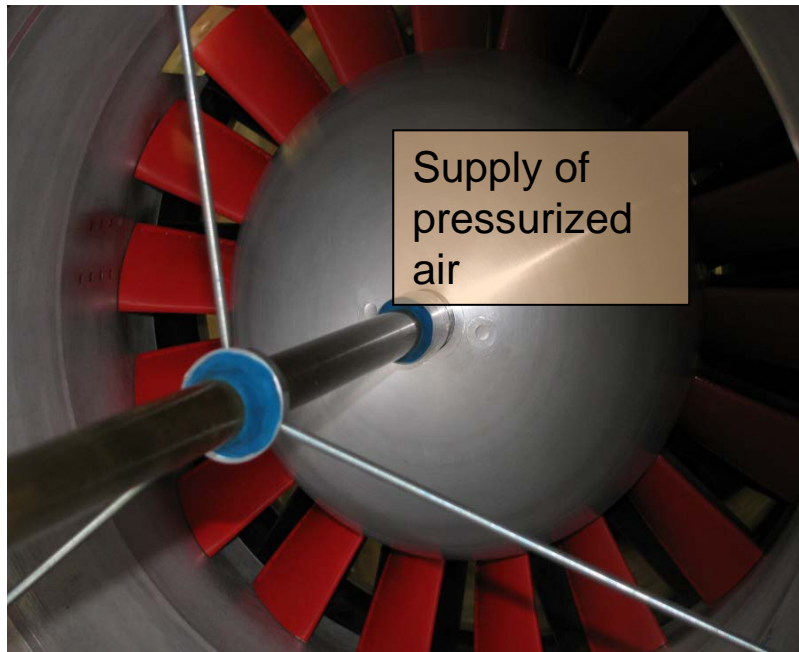


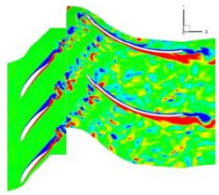
FLOCON

Boundary layer suction

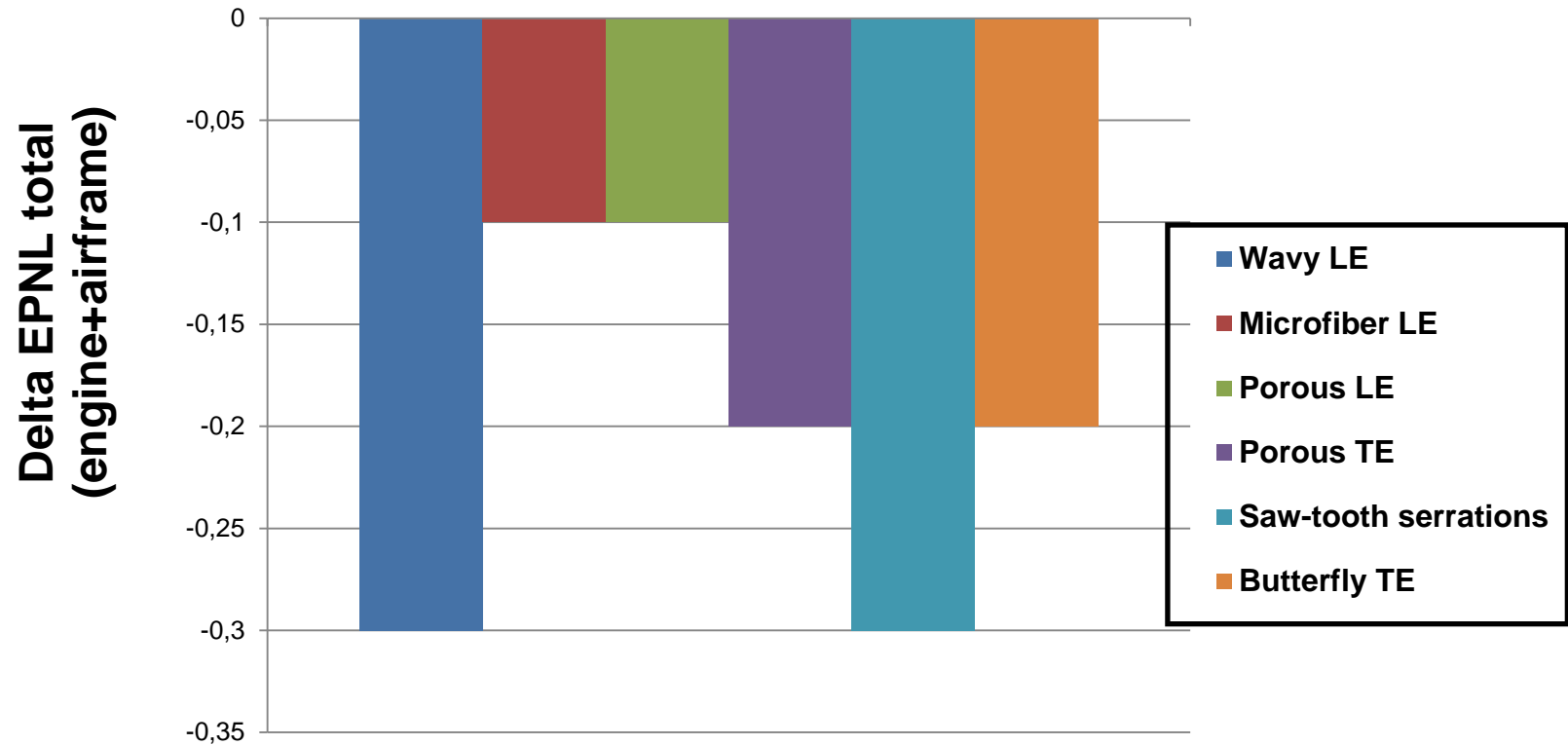


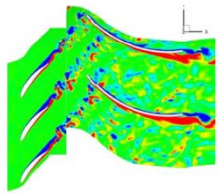
Experimental assessment of the wake filling



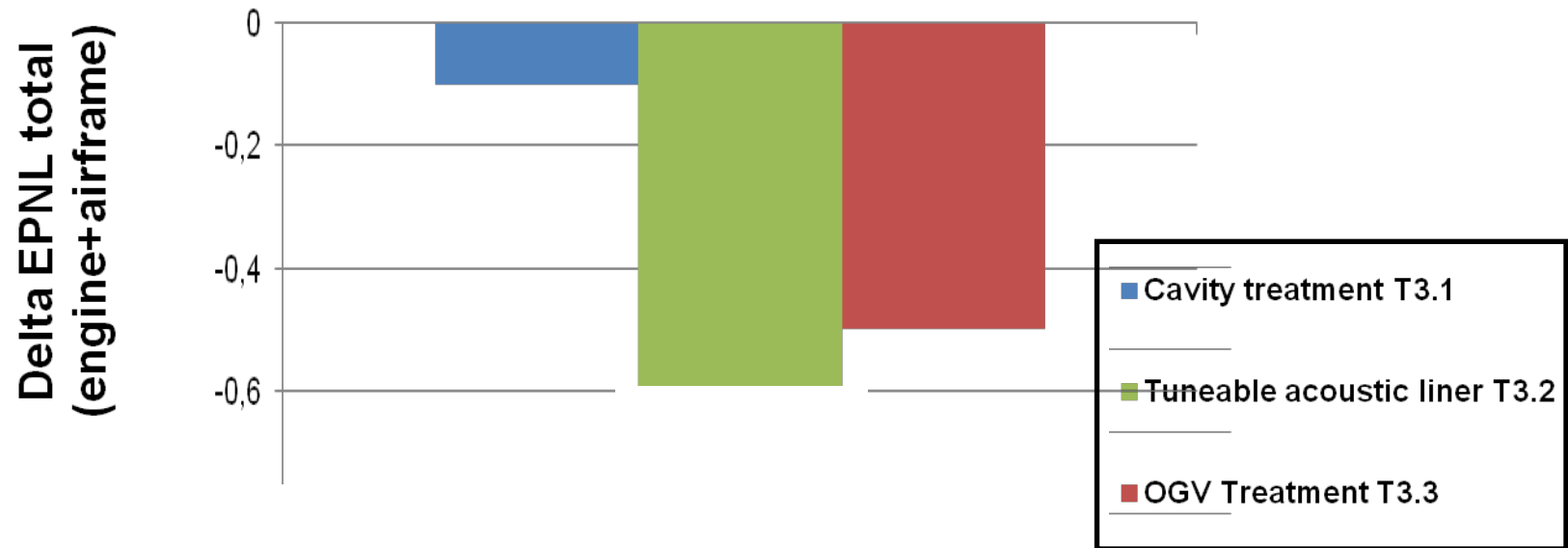


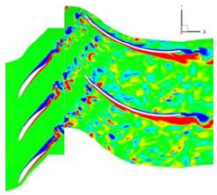
FLOCON technologies impacts
EPNL total (engine + airframe) WP2





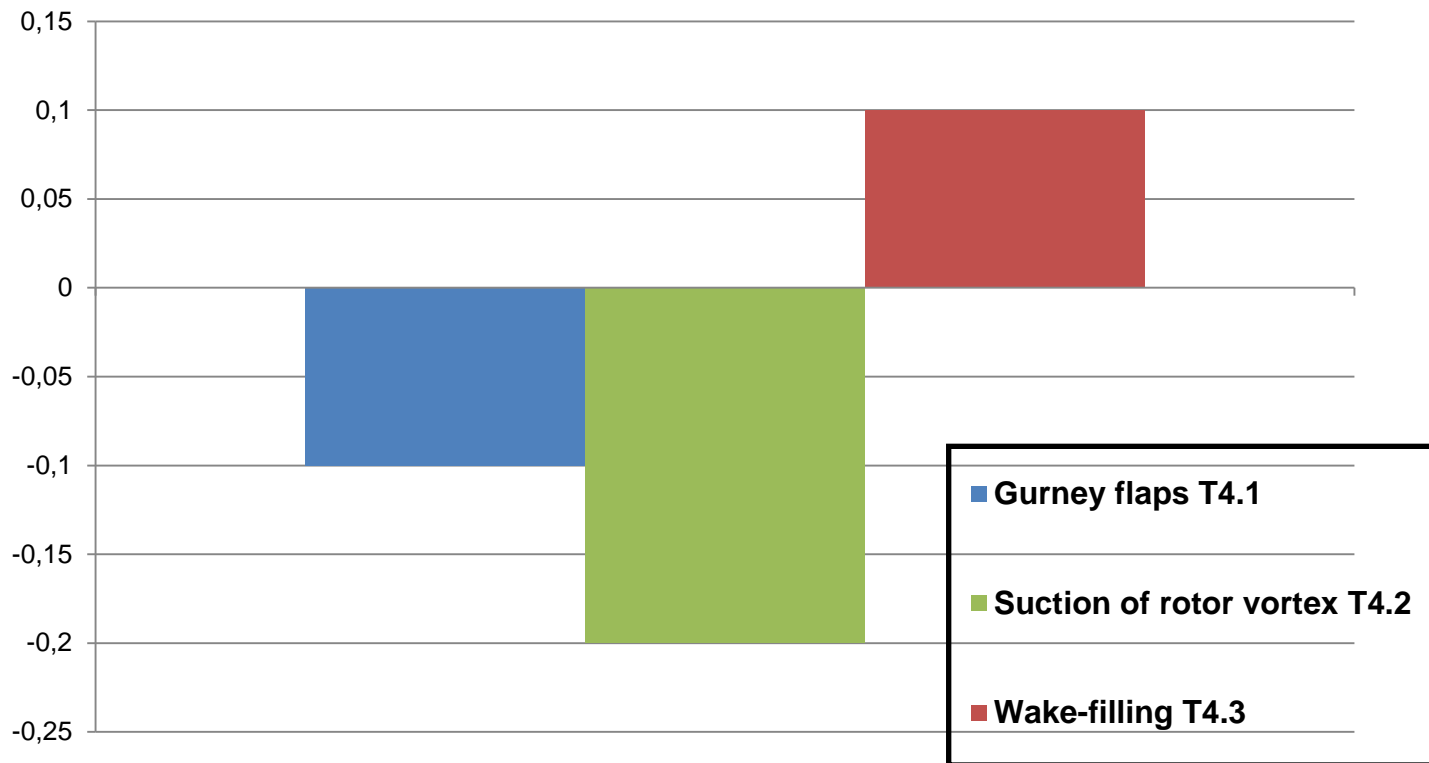
FLOCON technologies impacts EPNL total (engine + airframe) WP3

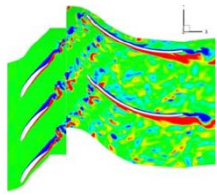




FLOCON technologies impacts EPNL total (engine + airframe) WP4

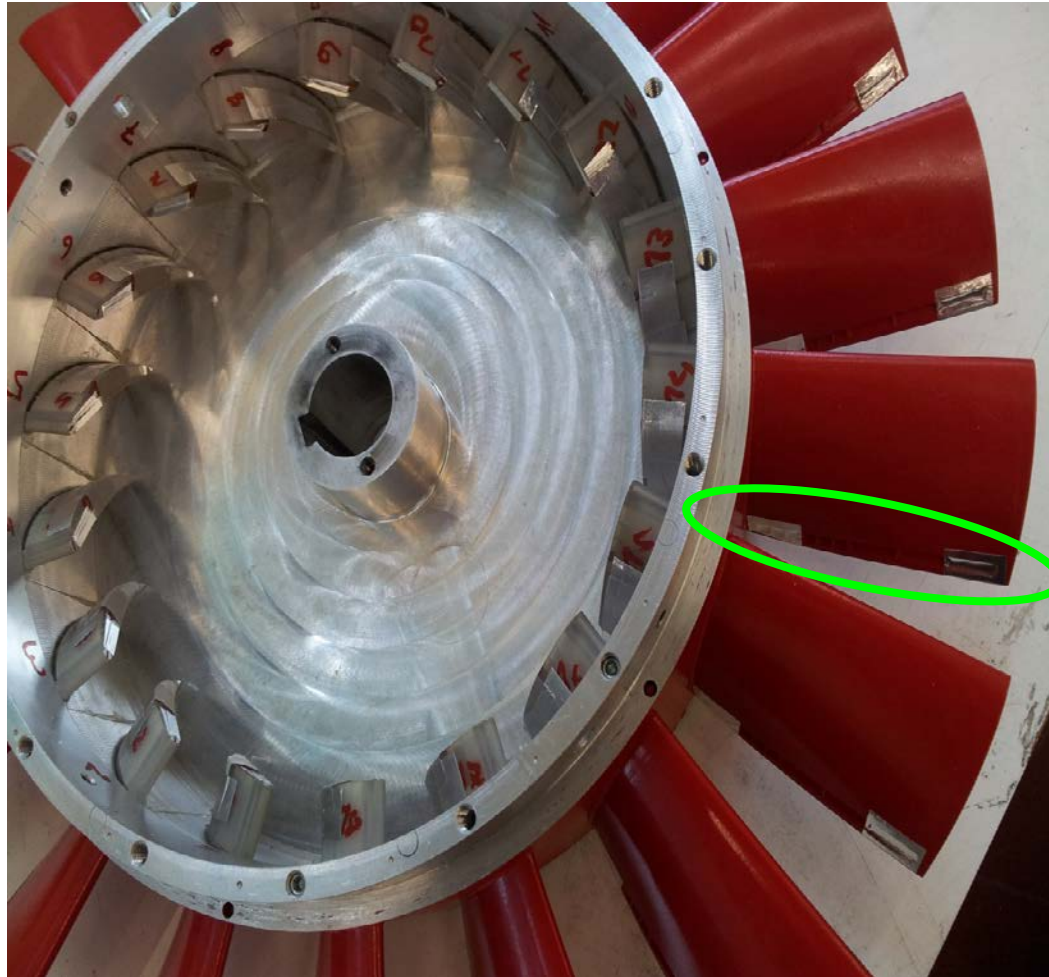
Delta EPNL total
(engine+airframe)

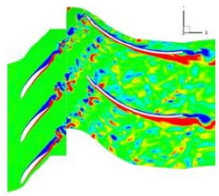




FLOCON

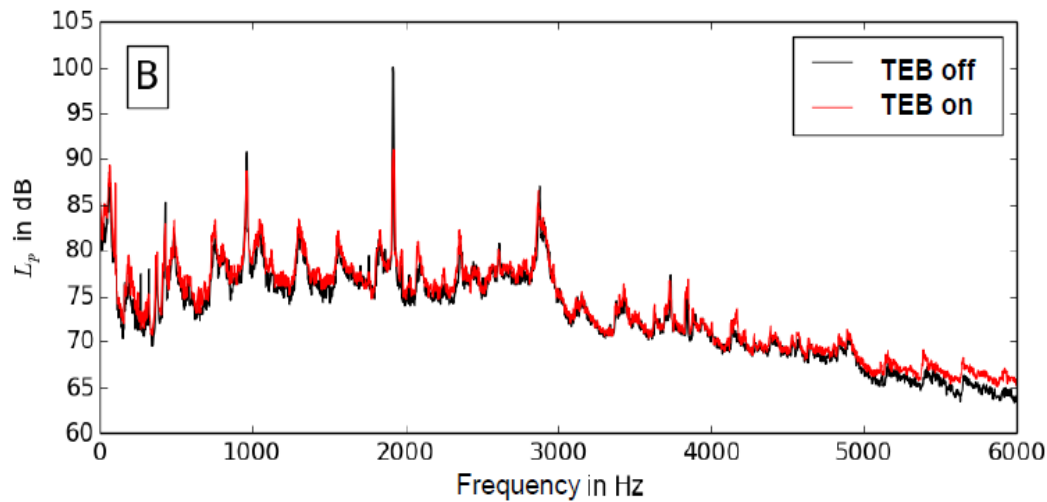
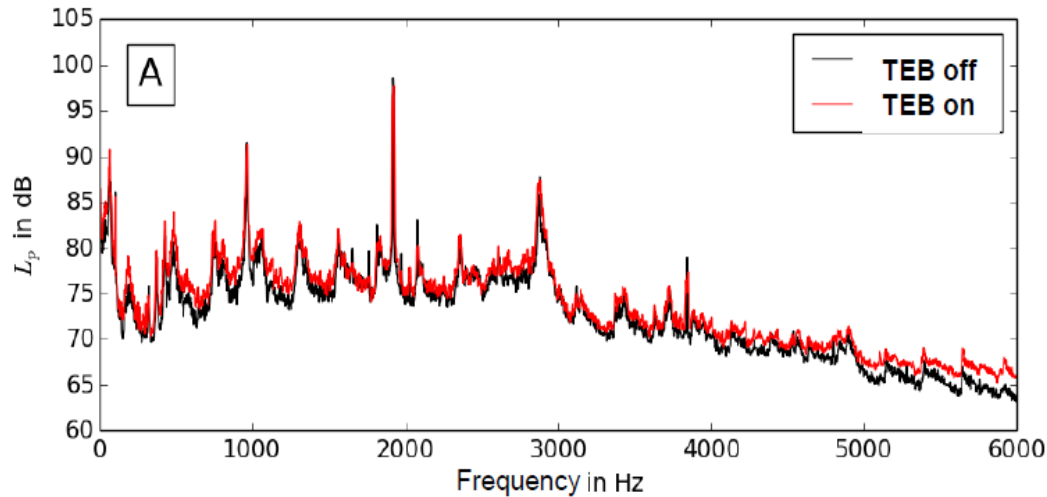
Wake filling (post FLOCON)



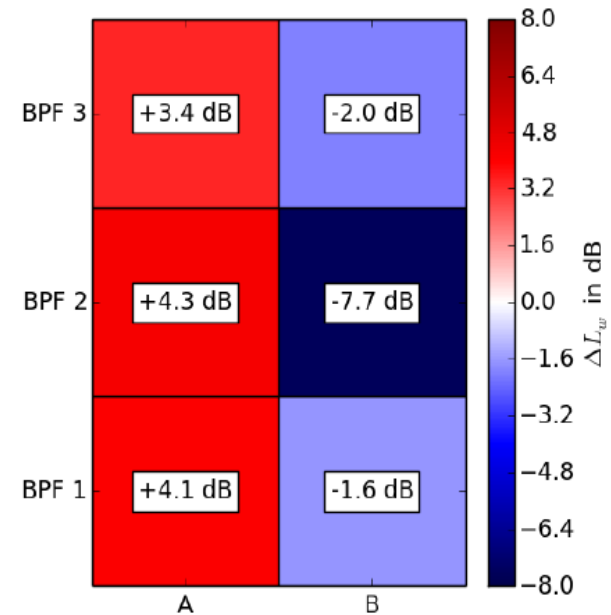


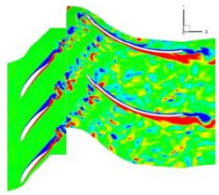
FLOCON

Wake filling (post FLOCON)

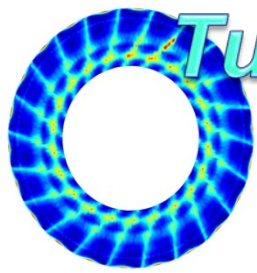


$U = 3200 \text{ min}^{-1}$
 $\varphi = 0,20$





- A wide range of concepts was considered and developed to Technology Readiness Level 4 (laboratory scale validation):
 - **Rotor trailing edge blowing**
 - **Rotor tip vortex suction**
 - **Rotor overtip treatments**
 - **Rotor and Stator leading and trailing edge treatments**
 - **Partly lined stator vanes**
- Experiments were performed on 4 rigs: two rotating rigs, supported by more detailed measurements on a single airfoil and on a cascade.
- Numerical methods were used to optimize the concepts for experimental validation and to extrapolate the results from laboratory scale to real engine application.



TurboNoiseBB

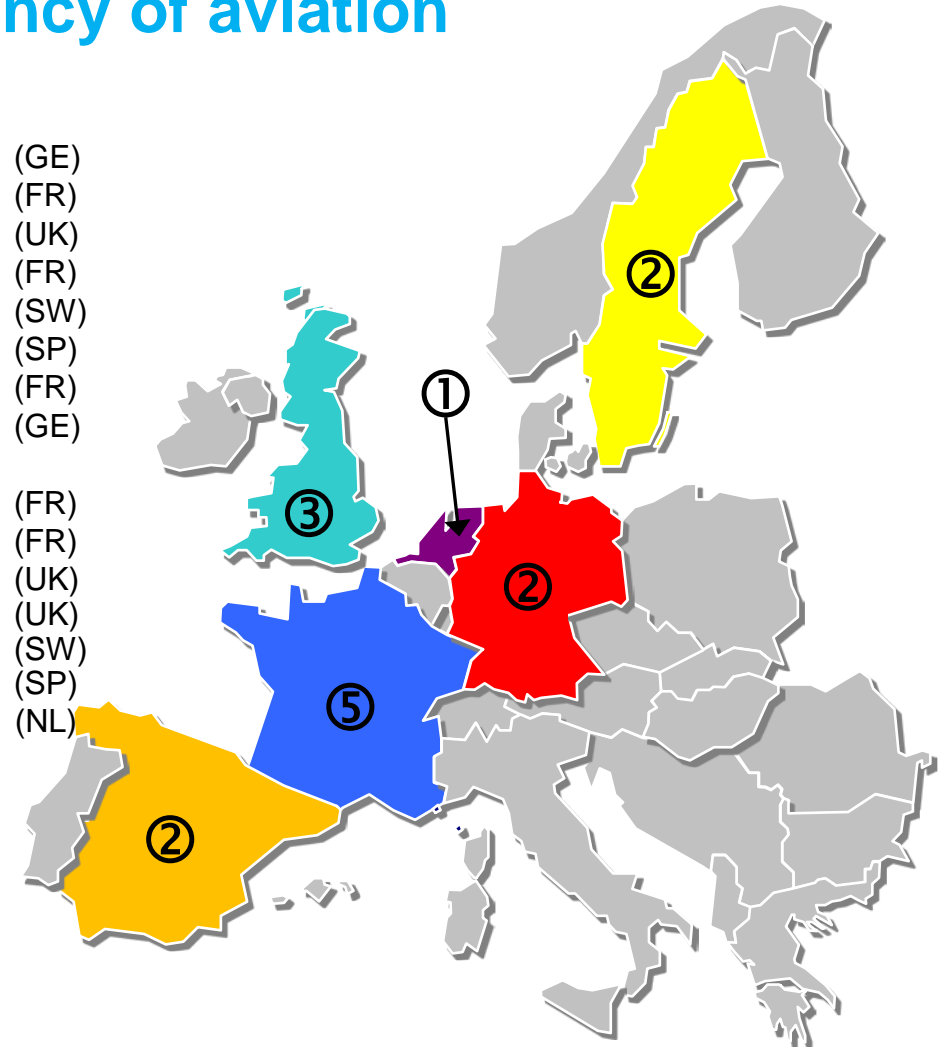
EU HORIZON 2020, Enhancing resource efficiency of aviation



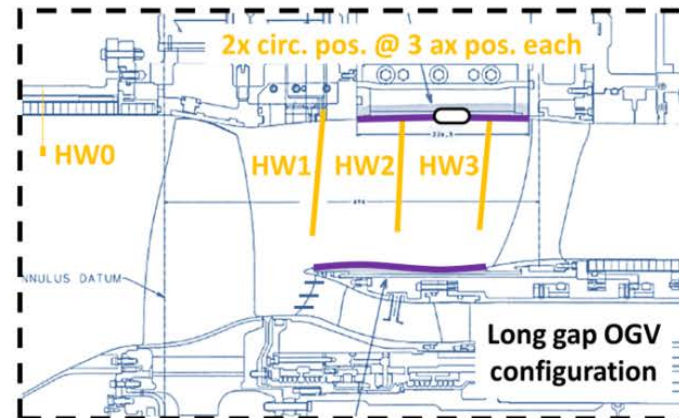
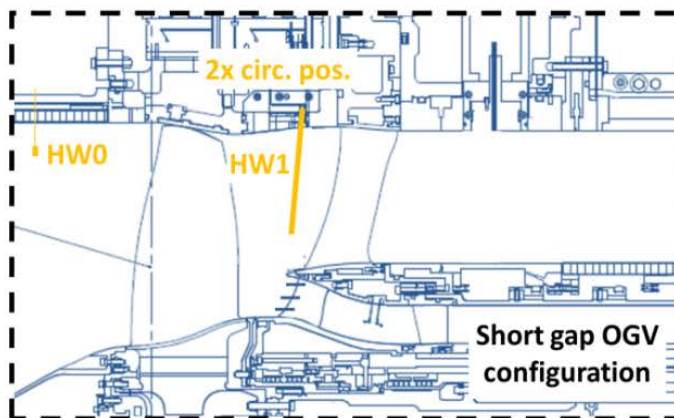
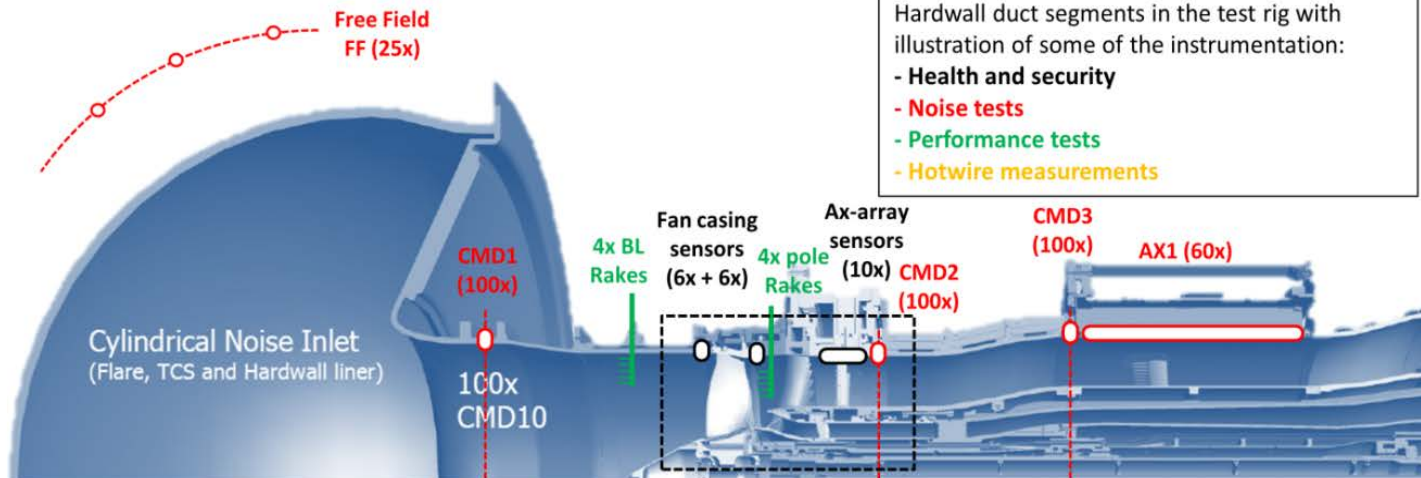
Consortium:

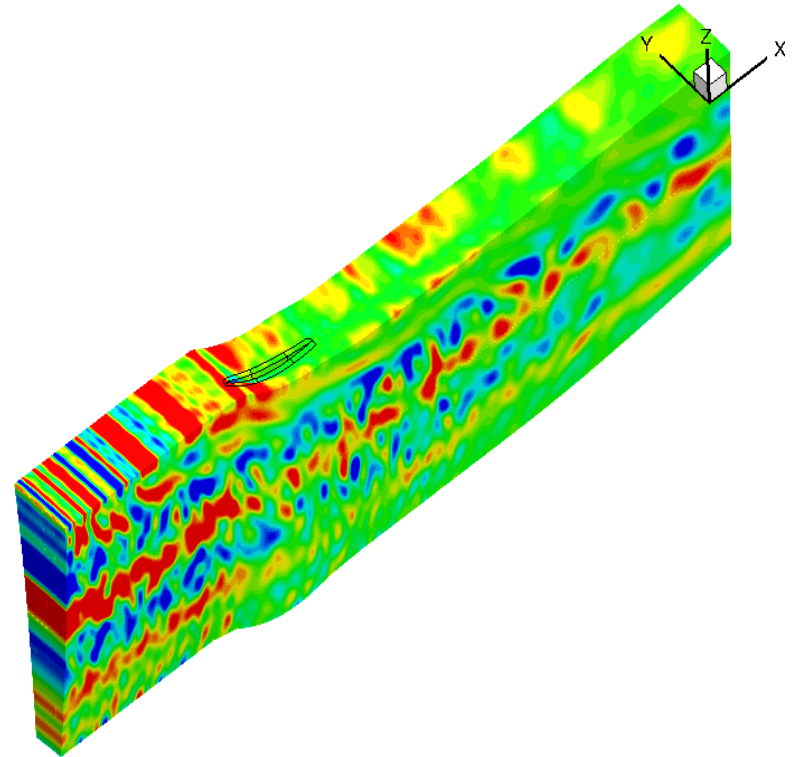
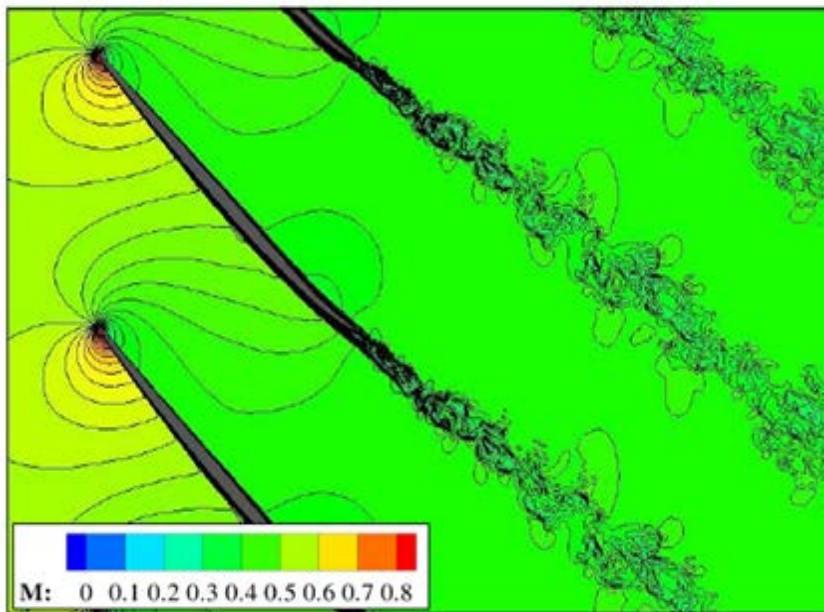
DLR - Deutsches Zentrum für Luft und Raumfahrt
Safran Aircraft Engines
Rolls-Royce plc
Airbus Operations S.A.S.
GKN Aerospace Engine Systems
ITP
Safran Helicopter Engines
MTU Aero Engines AG
ONERA - Office National d'Études et Recherches
Aérospatiales
Ecole Centrale de Lyon
University of Southampton
University of Cambridge
Chalmers University of Technology
Universidad Politécnica de Madrid
NLR - Nationaal Lucht- en Ruimtevaart Laboratorium

- **EU funding: 6.7 M€**
- **Call: MG-1.2-2015**
- **Project start: 1. September 2016**
- **Duration: 3.5 years**
- **Coordination: DLR Berlin**

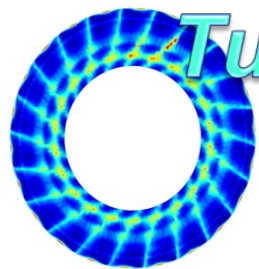


Rig set-up and sensor configuration



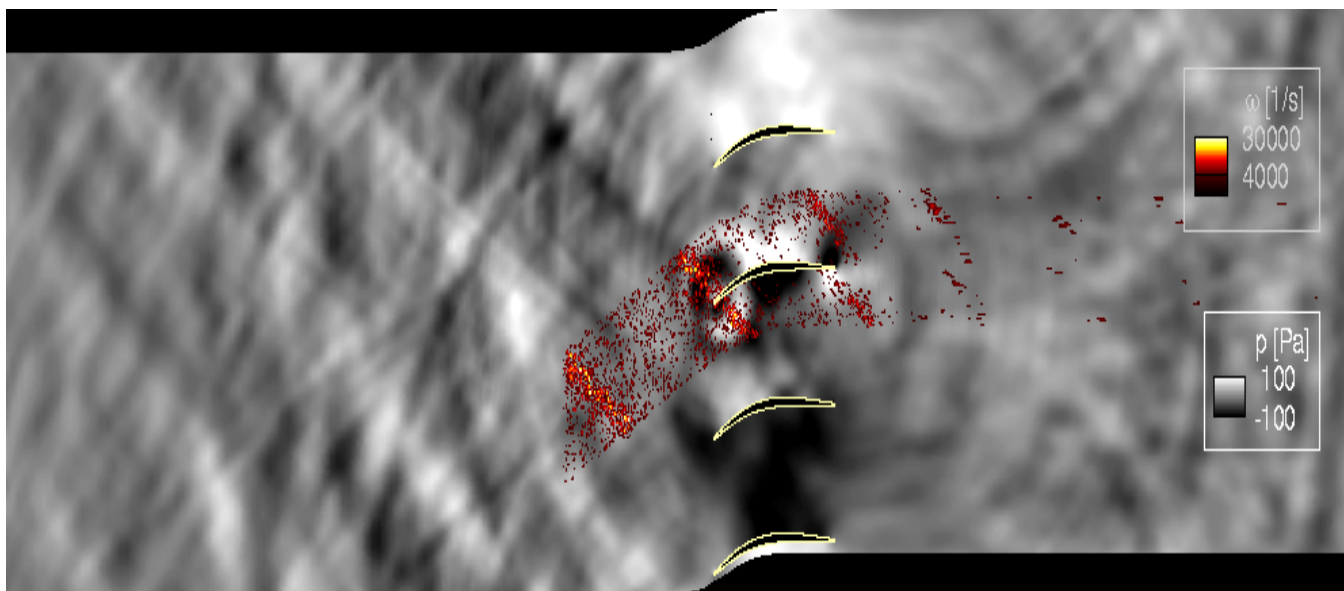


Numerical results by ONERA



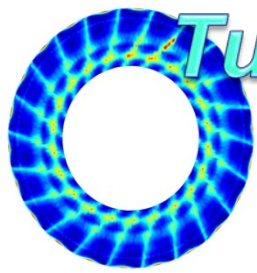
TurboNoiseBB

Random Particle Mesh simulation of rotor-wake-stator interaction broadband noise



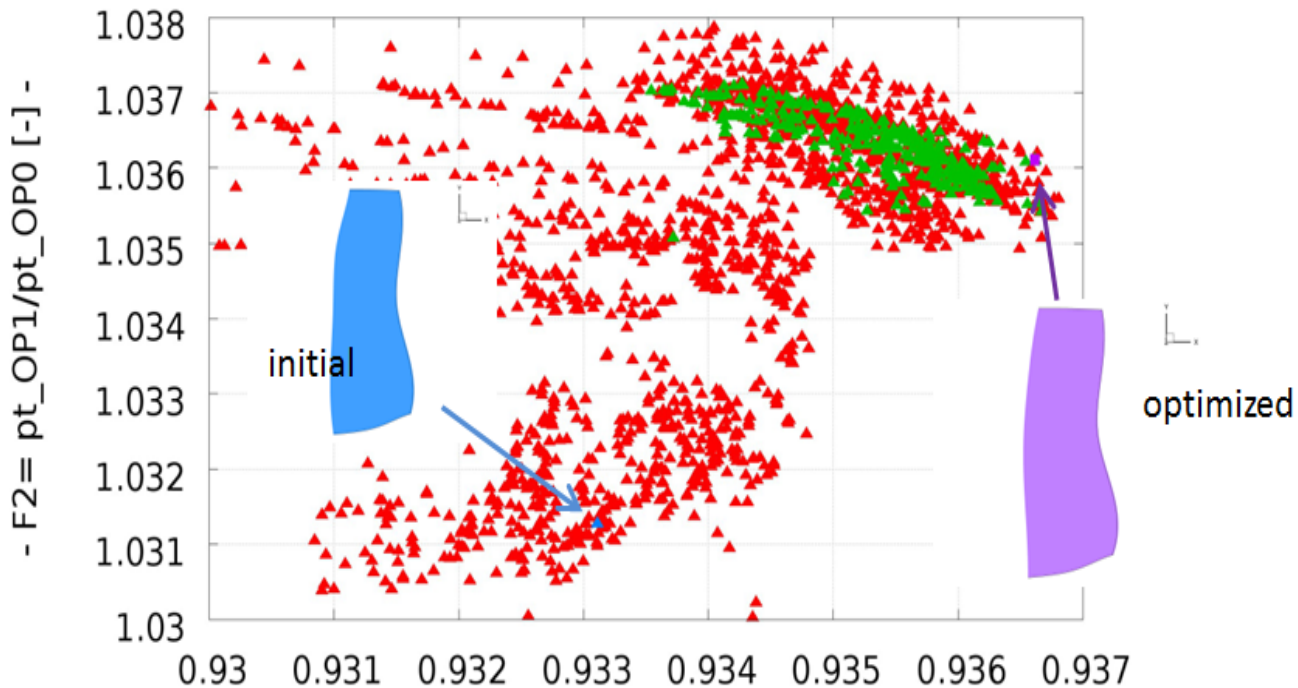
Numerical result by DLR

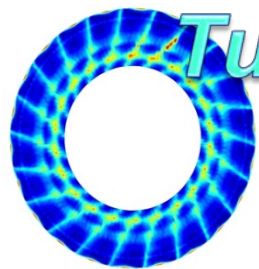




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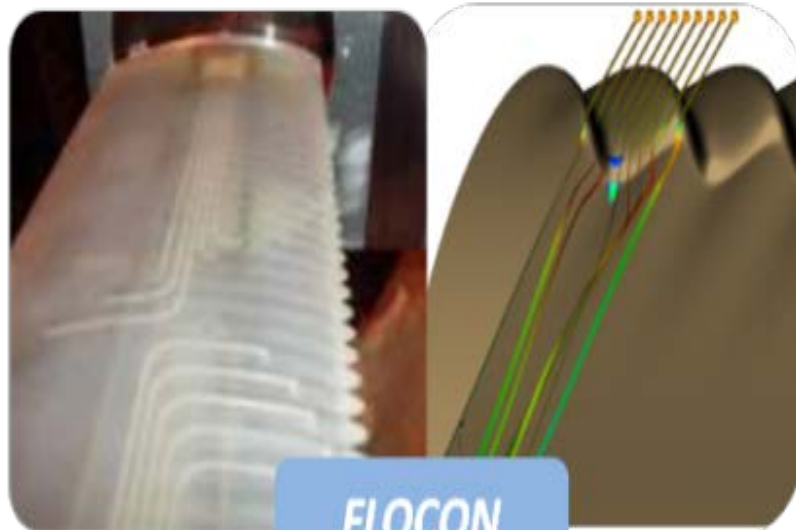
Optimised low broadband noise aero-mechanical design





TurboNoiseBB

Advanced and innovative low noise
OGV design

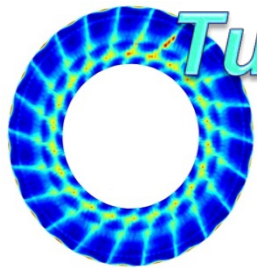


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Expected final results

- **Two potential aircraft / engine combinations** as representatives of future short-medium range and long range aircraft products equipped with the novel low noise designs **will be assessed**.
- The obtained **database** will provide the aerodynamic and aeroacoustic **input to fan broadband noise prediction methods**
- Accurate **unsteady flow and noise prediction methods will be validated** for the fan wake at different design certification conditions
- The high fidelity CFD / CAA **prediction methods for fan broadband noise sources** will be integrated into existing key system capabilities **for system-level multi-disciplinary optimisation**

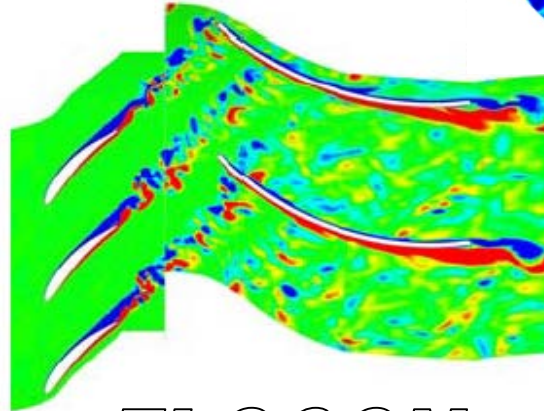




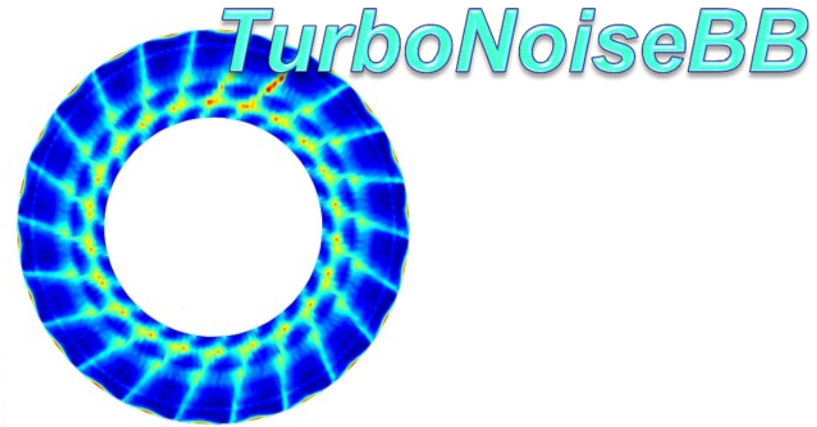
Acknowledgements



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